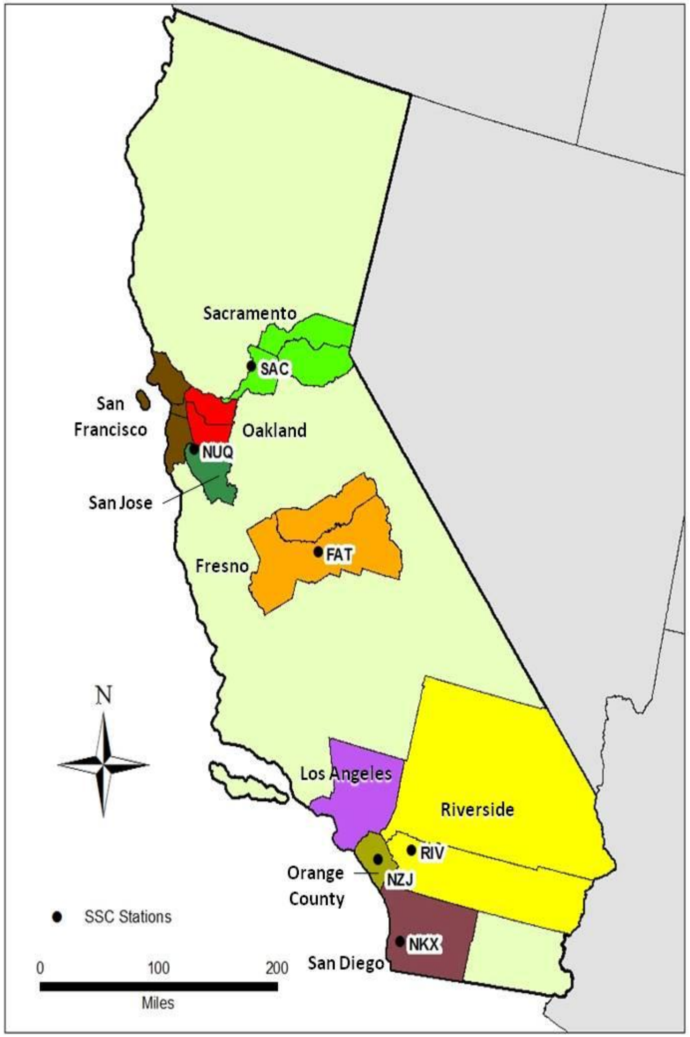
A Spatial Synoptic Classification approach to projected heat vulnerability in California under future climate change scenarios

Scott Sheridan, Kent State University
Cameron Lee, Kent State University
Michael Allen, Kent State University
Laurence Kalkstein, University of Miami

Presented to the California Air Resources Board
17 February 2011

Project Overview

We develop robust estimates of changes in ‘oppressive’ weather conditions and heat-related mortality through the 2090s for major urban regions in California.



The nine Urbanized Regions

Region	Largest City	Counties	Population (2000)
Fresno	Fresno	Fresno, Madera	922,516
Los Angeles	Los Angeles	Los Angeles	9,519,338
Oakland	Oakland	Alameda, Contra Costa	2,392,557
Orange	Santa Ana	Orange	2,846,289
Riverside	Riverside	Riverside, San Bernardino	3,254,821
Sacramento	Sacramento	El Dorado, Placer, Sacramento	1,628,197
San Diego	San Diego	San Diego	2,813,833
San Francisco	San Francisco	Marin, San Francisco, San Mateo	1,731,183
San Jose	San Jose	Santa Clara	1,682,585

Regions represent over 80% of California's population

Figures based on United States Census, 2000

The synoptic climatological approach

- Holistic approach: weather types or air masses
- Already in use in heat warning systems
- Use output that GCMs model relatively well (broad upper atmospheric thermal and circulation patterns) for downscaling

Accounting for uncertainty

- Greenhouse-gas emissions

  3 emissions scenarios used

- Population

  3 scenarios + no-growth scenario used

- Model bias

  2 GCMs used

- Acclimatization / adaptation to heat

  No acclimatization + 2 models used

Project Outline

1. Project historical and future *atmospheric patterns* and *surface weather types* across the state
2. Assess the historical connection between weather types and heat-related mortality across the state
3. Use these relationships to project future heat-related mortality

Project Outline

1. Project historical and future *atmospheric patterns* and *surface weather types* across the state
   - **Data sets**
   - Methodology
   - Historical and future patterns and weather types

Obtained Data Sets

	Historical	Future
Atmospheric data	**Obtained:** Reanalysis and GCM 20th Century modeled	**Obtained:** GCM Future modeled
Surface weather type data (SSC)	**Obtained:** from SSC webpage	**?**

Atmospheric Data

Variables

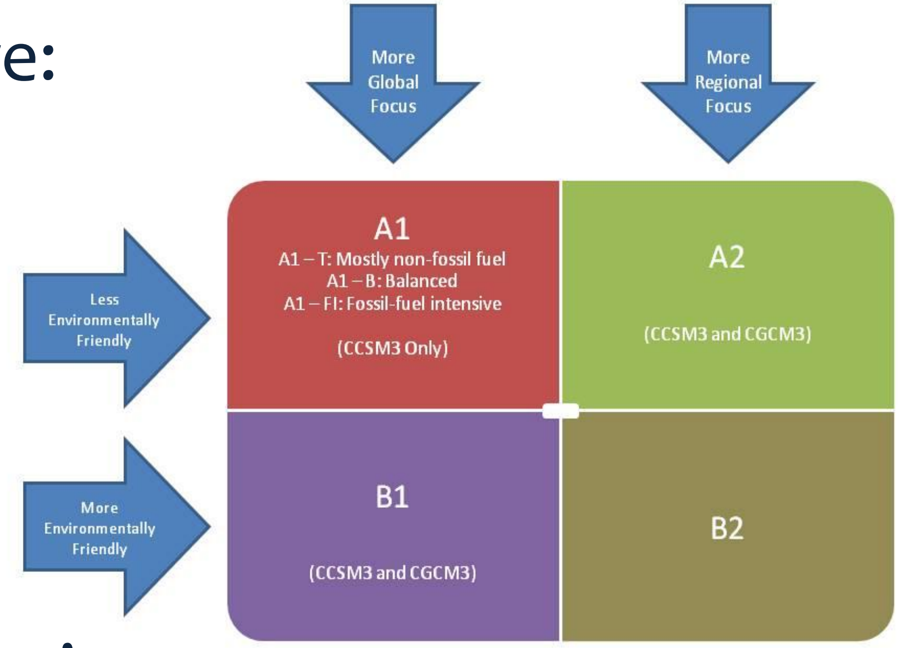
- Daily Fields:
  - **500 mb geopotential heights**
    (circulation at about 5500 m)
  - **700 mb geopotential heights**
    (circulation at about 3000 m)
  - **850 mb temperature**
    (temperature at about 1500 m)

Data Sets

- NCEP/NCAR Reanalysis (NNR)
  - 1957 – 2002
  - Considered 'observed' data
- Global Climate Models (GCMs)
  - CCSM3
    - Historical (1957-2002)
    - Future (A1FI, A2, B1)
  - CGCM3
    - Historical (1960-1999)
    - Future (A2, B1)

SRES Scenarios

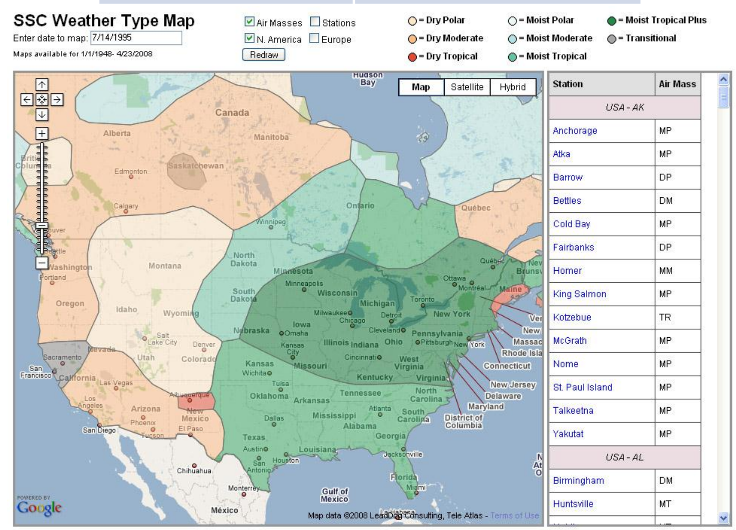
- Represent different futures based on:
  - Economic development, pace of globalization, carbon intensity, & population growth
- Three scenarios used here:
  - A1FI – Higher-emissions
    - CCSM3 only
  - A2 – Intermediate
    - Both GCMs
  - B1 – Lower-emissions
    - Both GCMs
- Creates 5 ‘model scenarios’



The Spatial Synoptic Classification (SSC)
(Sheridan 2002)

- At each station, classifies each day into one of several ‘weather types’
- Based on: temperature, dew point, sea level pressure, wind, cloud cover

Abbreviation	Weather Type
DM	Dry Moderate
DP	Dry Polar
DT	**Dry Tropical**
MM	Moist Moderate
MP	Moist Polar
MT	**Moist Tropical**
TR	Transitional



SSC conditions vary, seasonally and spatially

	DRY TROPICAL			MOIST TROPICAL		
	Frequency	2pm Temperature	2 pm Dew Point	Frequency	2pm Temperature	2 pm Dew Point
MIRAMAR (SAN DIEGO)						
April	7%	81	38	20%	73	56
June	3%	91	48	9%	81	60
August	2%	91	56	23%	84	66
SACRAMENTO						
April	12%	77	40	2%	77	54
June	23%	94	50	<1%		
August	24%	95	54	<1%		

Two weather types - Dry Tropical (DT) and Moist Tropical (MT) - are most often associated with increased mortality (Sheridan and Kalkstein, 2004; Sheridan et al. 2009)

SSC locations to include

- Final stations selected after substantial testing
  - SSC must be predictable from upper-atmospheric circulation patterns for future
  - Extreme coastal stations affected by sea breeze
    - Difficult to predict SSC from upper-atmospheric patterns
    - LAX, SFO, SAN replaced by NZJ, NUQ, NKX

Station Name	Code	Regions
El Toro (Irvine)	NZJ	Los Angeles, Orange
Fresno	FAT	Fresno
Miramar (San Diego)	NKX	San Diego
Moffett Field (Mountain View)	NUQ	Oakland, San Francisco, San Jose
Riverside	RIV	Riverside
Sacramento	SAC	Sacramento

Project Outline

1. Project historical and future *atmospheric patterns* and *surface weather types* across the state
   - Data sets
   - **Methodology**
   - Historical and future patterns and weather types

Methods

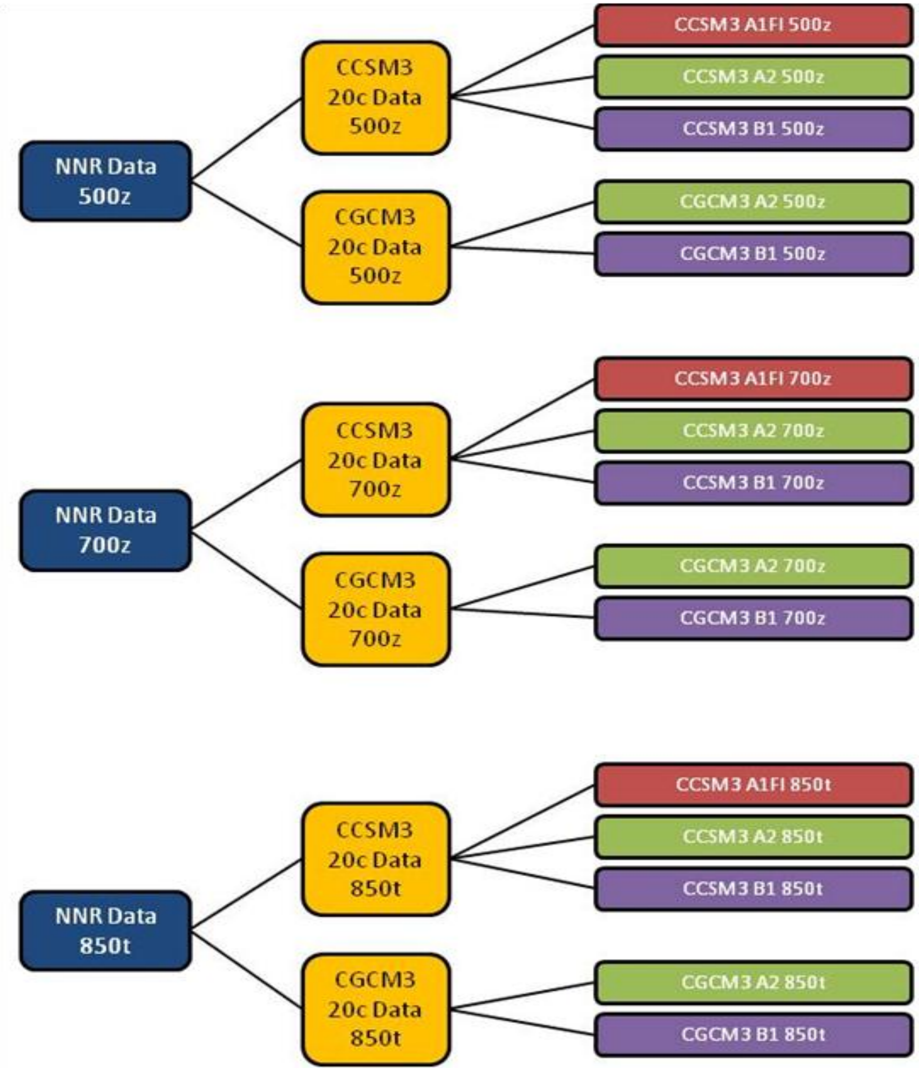
- Debiasing Data Sets
- Combining Data Sets
- Six-Step Method to create Patterns
- Relating Patterns to SSC Types

Debiasing Data Sets

- *debiasing* – removing the mean monthly model (GCM) bias at each grid point
  - Mean monthly difference between the model (GCM20c) and the ‘observed’ (NNR)
  - Better correlations between NNR patterns and GCM20c patterns ($r > 0.99$ for all)
  - Debiasing performed for all GCM data
    - 20th Century and Future

Combining Data Sets

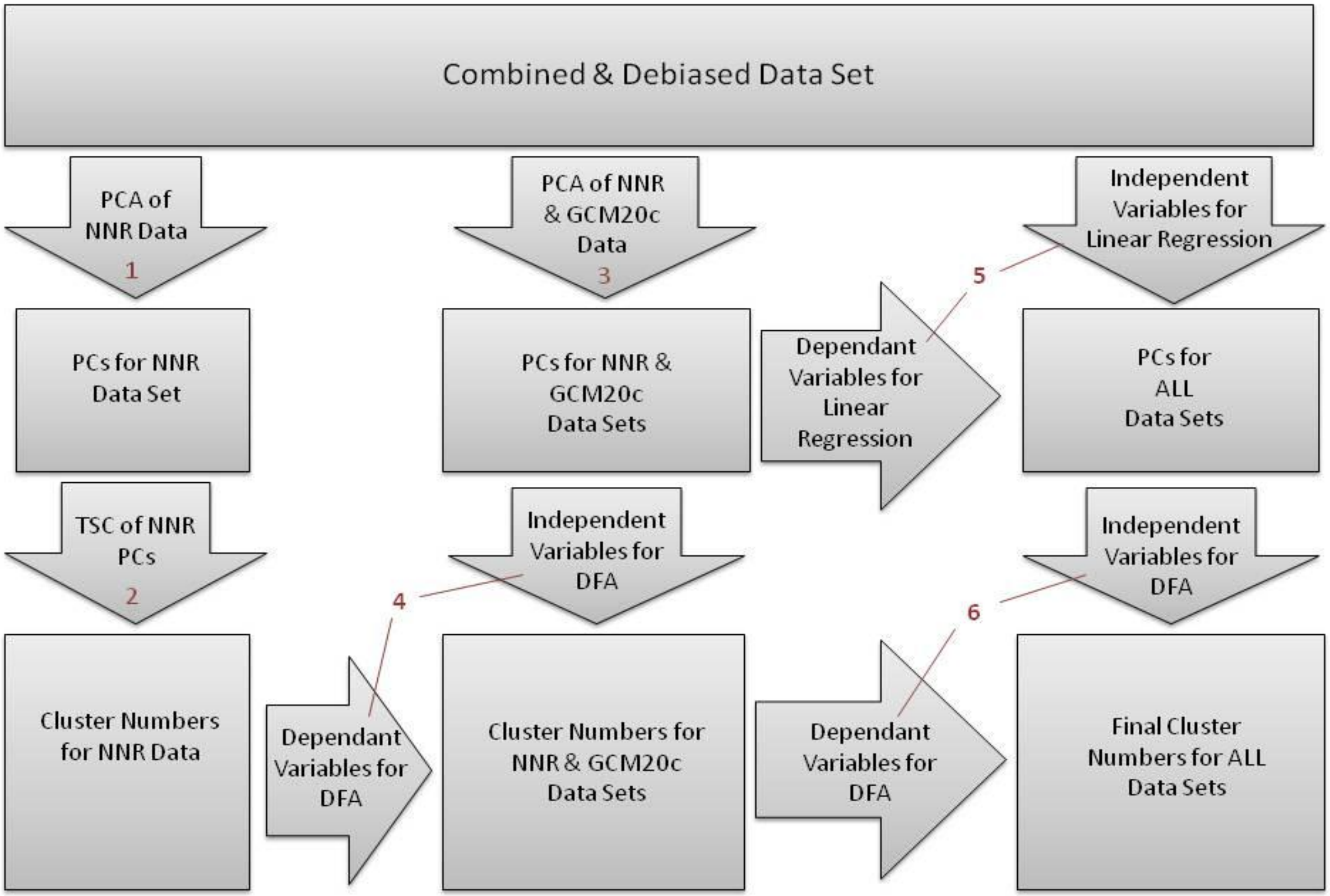
- 15 debiased data sets used for all future analysis
- Data confined to 9-month 'warm season'
  - March to November



Six-Step Method

- Classifies every day in the data set into one of 10 different patterns (or clusters)
  - NNR, GCM20c & all GCM Future Data
- Iterated once for each of the 15 data sets
  - 3 atmospheric levels by 5 model scenarios
- Future patterns are meant to resemble historical patterns as closely as possible
  - Changes in frequency & seasonality are focused on for future

Six-Step Method



Data Processing

- Cluster numbers for each level are combined into the same data set
  - Thus, there are now 5 data sets
    - One for each model-scenario

- Create new data sets for each of the 6 SSC stations used and for each of the 5 model scenarios
  - 30 total data sets for further analysis

Relating Patterns to SSC Types

- Multinomial Logistic Regression (MLR)
  - Determines relationship between SSC type & clusters, based upon the *historical* record
  - Predicts *future* SSC types based upon a set of atmospheric circulation patterns and other variables

- Two customized MLR methods used:
  - Inland MLR
  - Coastal MLR

Project Outline

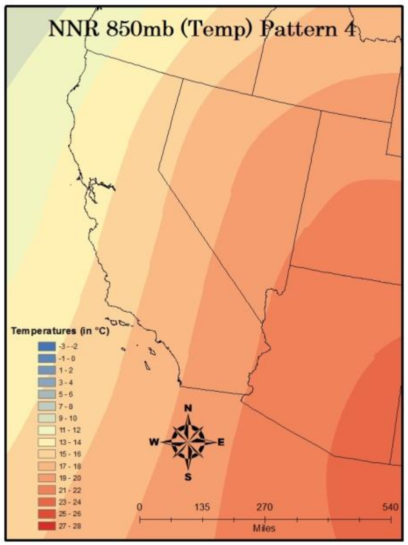
1. Project historical and future *atmospheric patterns* and *surface weather types* across the state
   - Data sets
   - Methodology
   - **Historical and future patterns and weather types**

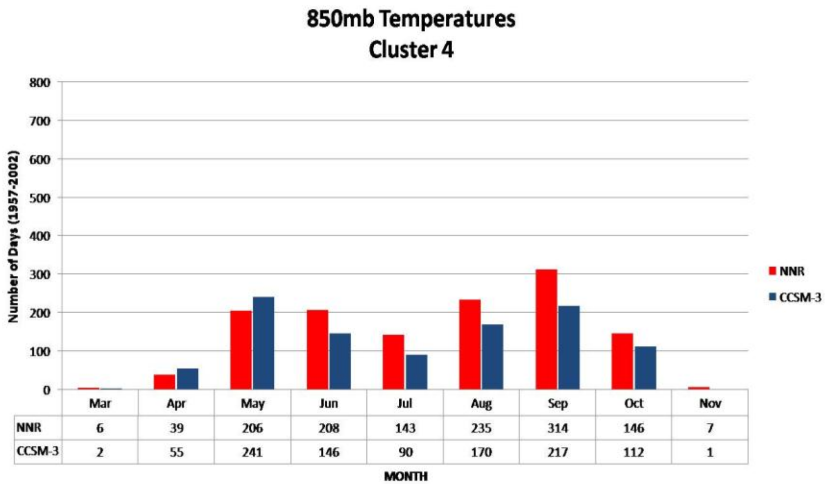
Historical Patterns

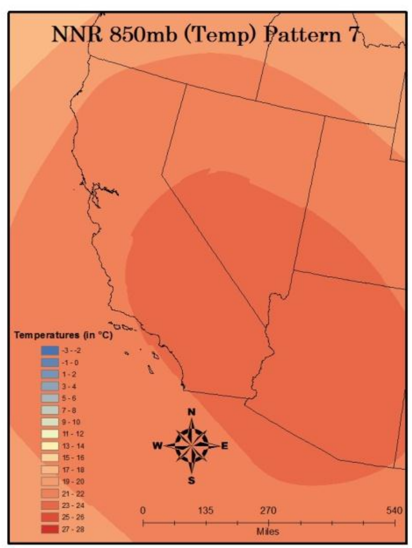
- 10 patterns classified for each level
  - 30 patterns total
- NNR patterns match up well with CCSM3 20th Century (GCM20c) patterns
  - Shape and Seasonality
- Clear summer-dominant patterns at each level

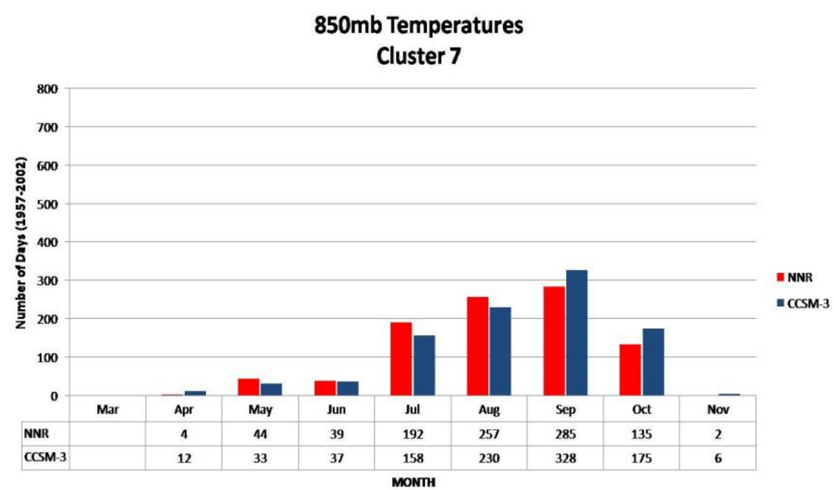
Historical Patterns

850MB TEMPERATURES

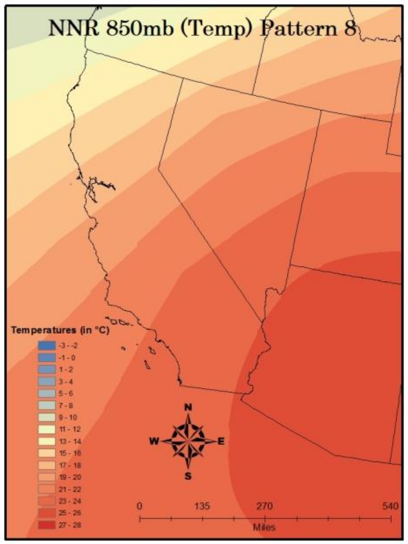


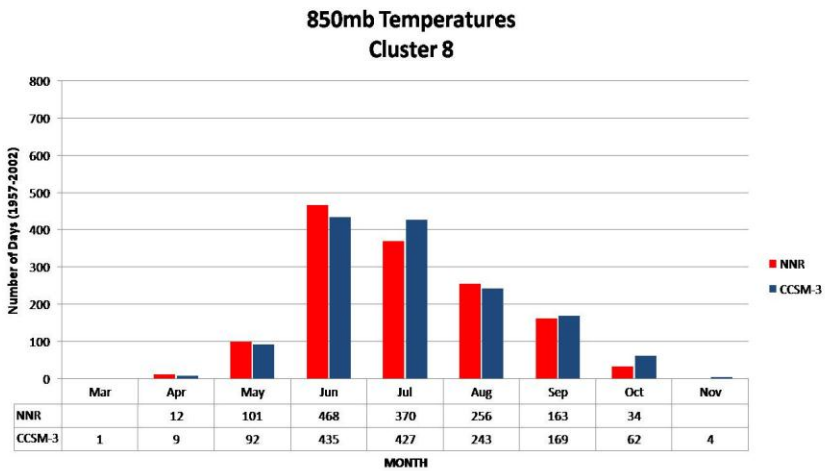


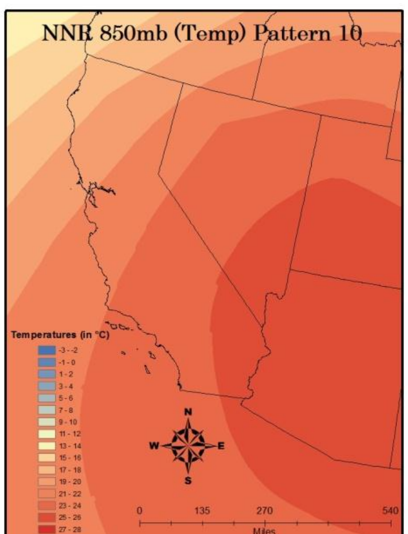


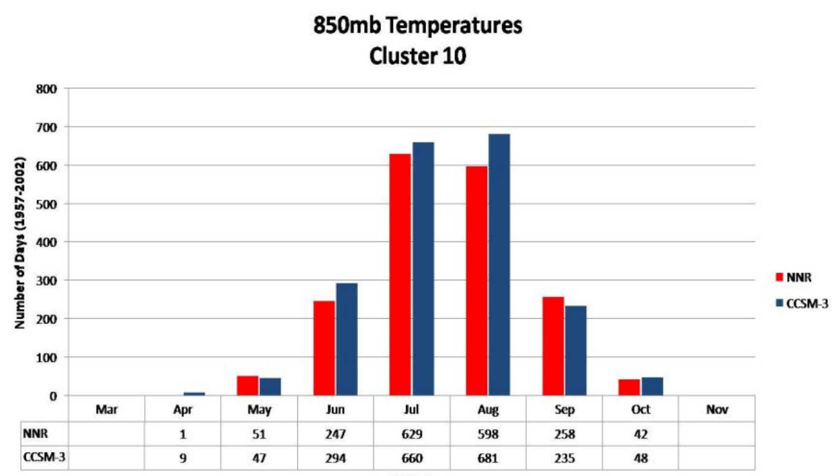


Historical Patterns
850MB TEMPERATURES





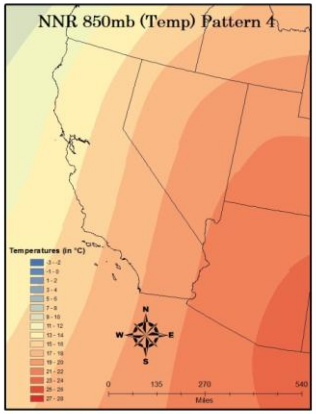




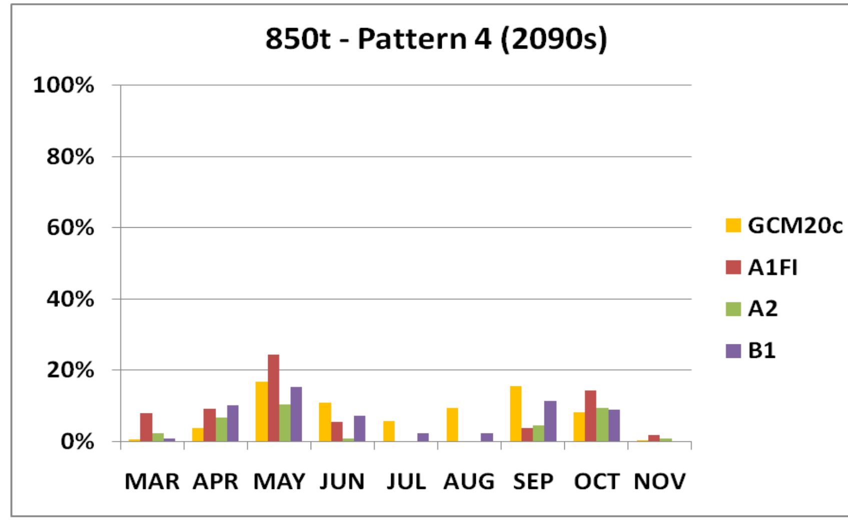
Future Patterns

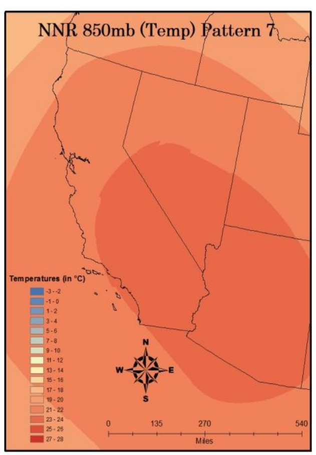
- Important changes to pattern frequency & seasonality in the future decades
  - Shifts in seasonality
  - Changes in Frequency
  - More pronounced changes in higher-emissions scenarios
  - More pronounced further into the future

Future Patterns
850MB TEMPERATURES

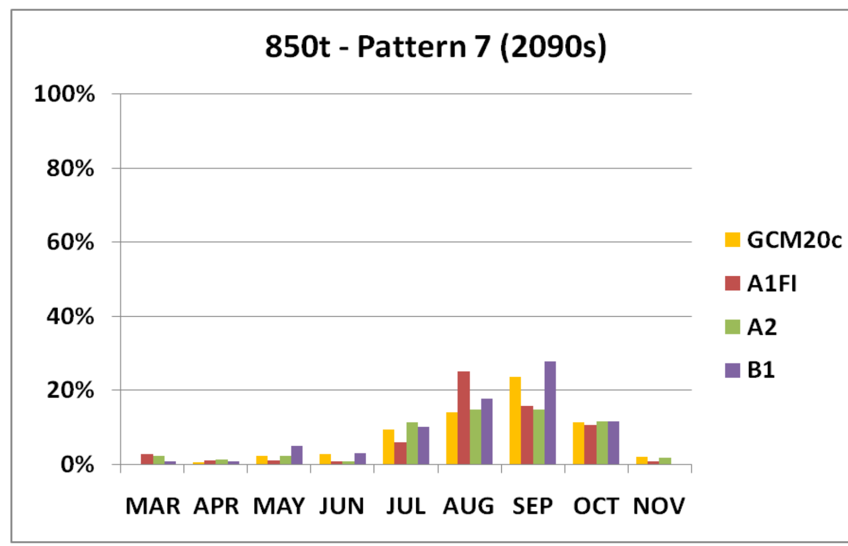


- Pattern 4:
  - Stronger influence in spring & autumn in the future
  - Becomes more rare in summer



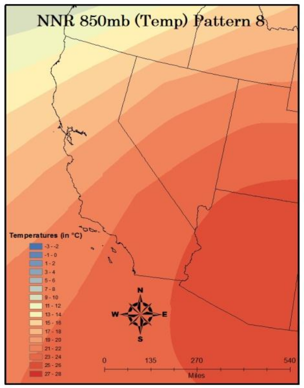


- Pattern 7:
  - Dominates in late summer
  - Peak in August in A1FI, peak in September in B1

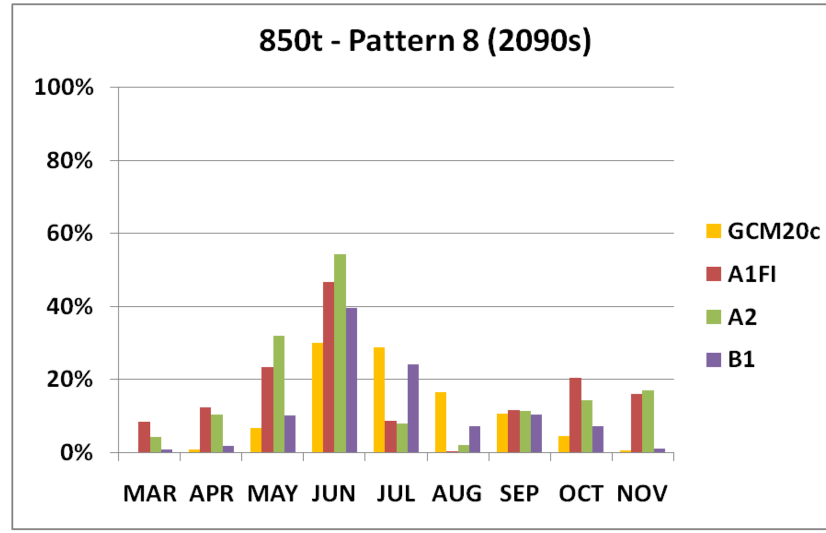


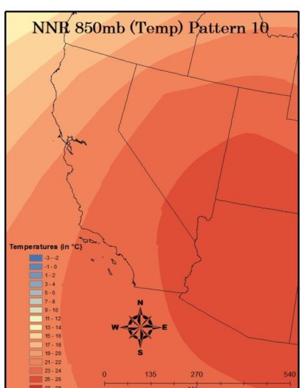
Future Patterns

850MB TEMPERATURES

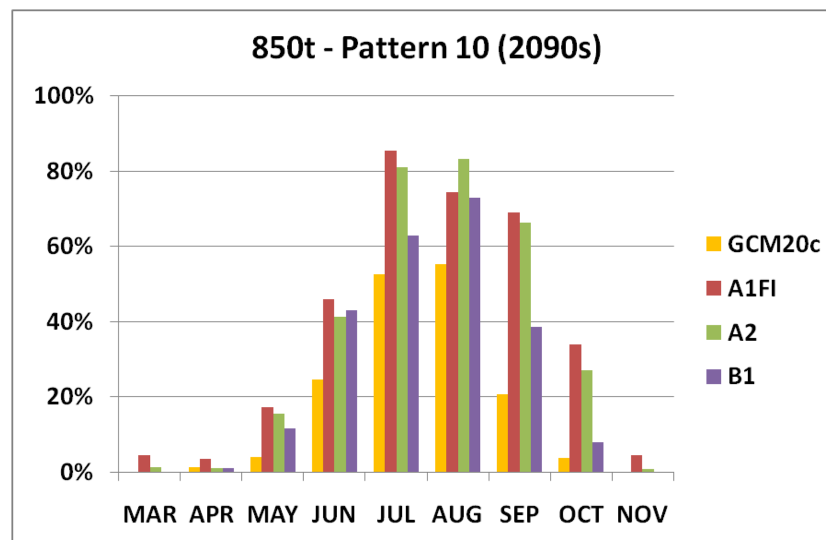


- Pattern 8:
  - Overall frequency increases
  - Dominates in late spring, and early summer by 2090s





- Pattern 10:
  - Largest frequency increase of all 850mb patterns
  - Under A1FI, occurs nearly 80% of July & August days



SSC Frequencies

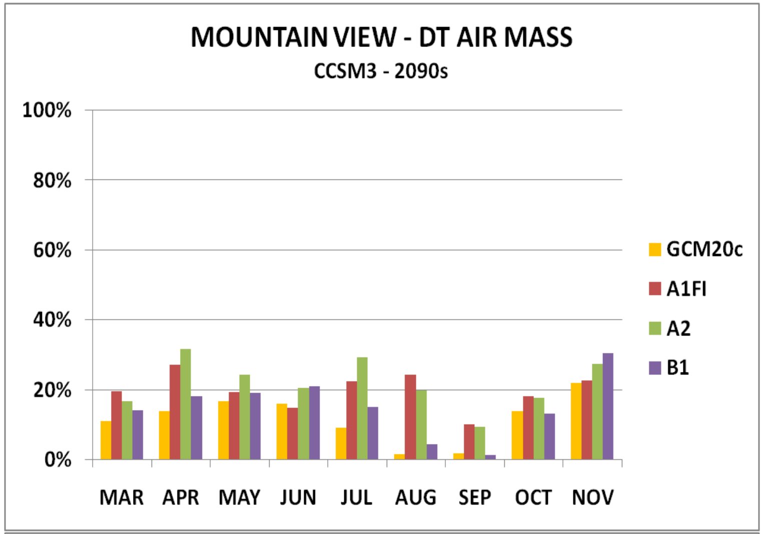
- Predicted separately for each SSC station
  - Six stations, representing nine urban areas in CA
- Predicted from circulation patterns & other variables using MLR
- Both GCMs (CCSM3 & CGCM3) duplicate SSC weather types with significant accuracy
- Focus here will be on DT & MT air masses and the CCSM3 results in the 2090s

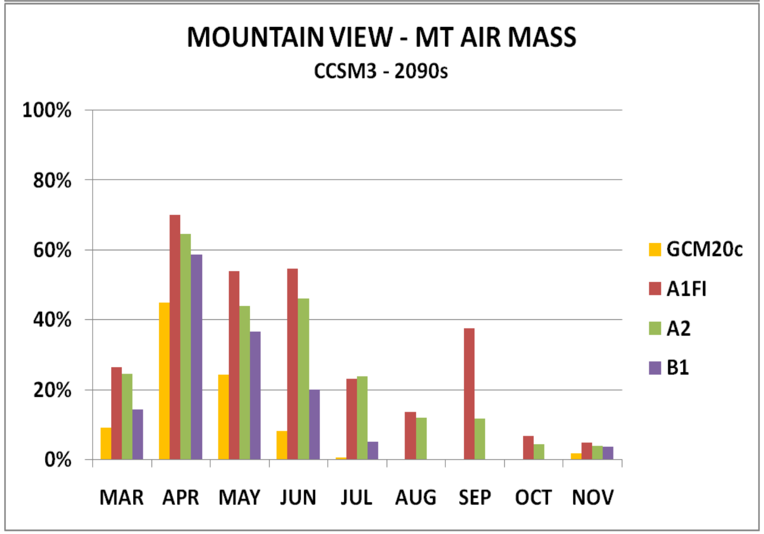
Annual SSC Frequencies and Model Bias

Station	SSC Type	ACTUAL AVG	CCSM3 20TH CENTURY AVG			
			NNR	NNR MODEL	GCM20c	GCM20c MODEL
Mtn. View	DT	7.6%	10.5%	2.8%	11.1%	3.5%
	MT	8.0%	8.8%	0.8%	9.1%	1.1%
El Toro	DT	10.8%	7.2%	-3.6%	7.7%	-3.1%
	MT	13.9%	9.1%	-4.8%	7.8%	-6.0%
Riverside	DT	29.7%	33.1%	3.4%	33.0%	3.3%
	MT	9.5%	5.9%	-3.6%	4.8%	-4.7%
Sacramento	DT	20.9%	19.9%	-1.0%	18.3%	-2.6%
	MT	1.8%	4.5%	2.8%	4.4%	2.7%

Future SSC frequency
MOUNTAIN VIEW (Bay Area)

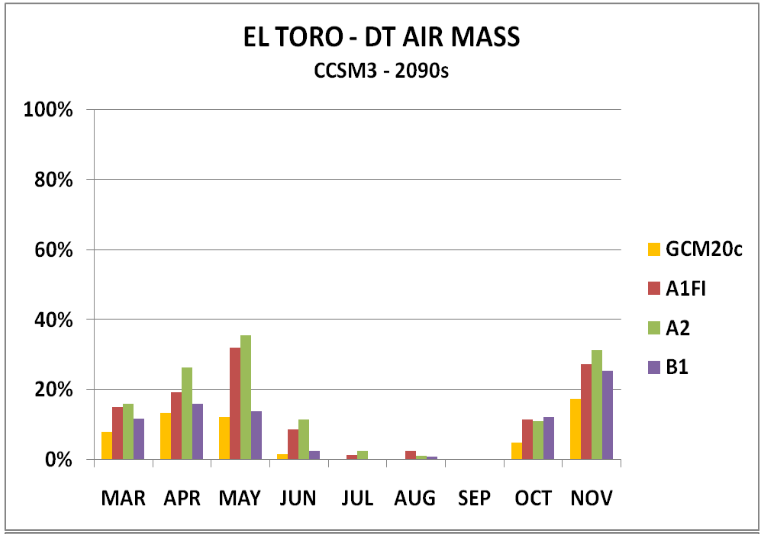
- DT occurs in spring and early summer
  - Slight increase in the future
- MT occurs often in the spring
  - Increases dramatically in every month
    - Strongest increases in spring and early summer
    - Largest increases in A1FI & A2

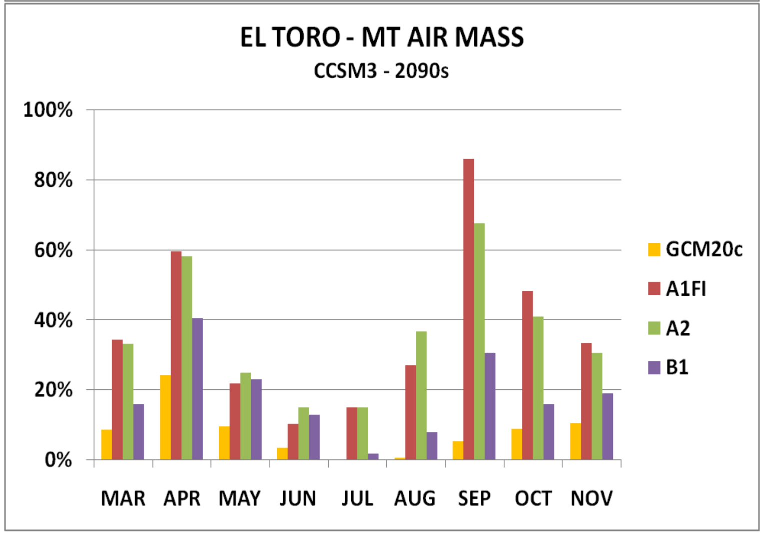




Future SSC frequency
EL TORO (LA & Orange County)

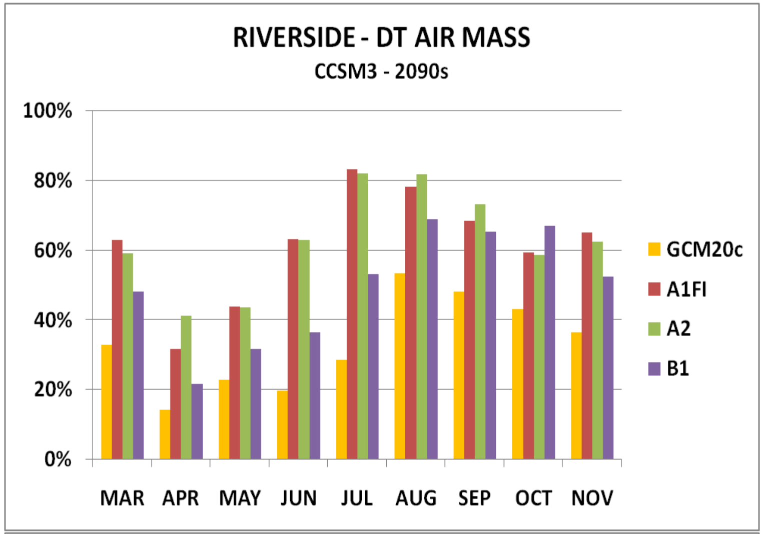
- DT occurs in spring and autumn at present
  - Projected to increase in all months, especially May
- MT has similar seasonality presently
  - Drastic future increases in MT in all months
  - Increases in September MT are over 20-fold
  - Largest increases are for A1FI & A2



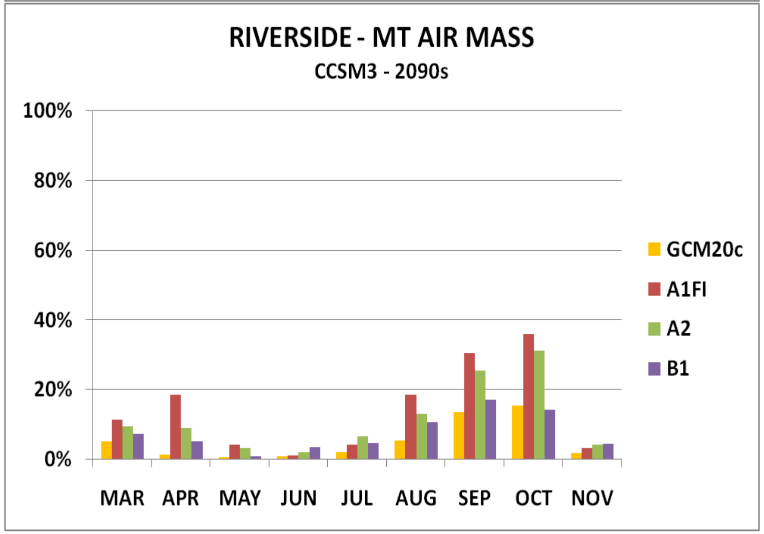


Future SSC frequency
RIVERSIDE

- DT dominates all warm-season
  - Projected to rise sharply in all months
    - Especially early summer in A1FI & A2
  - Could account for nearly 70% of summer days in future

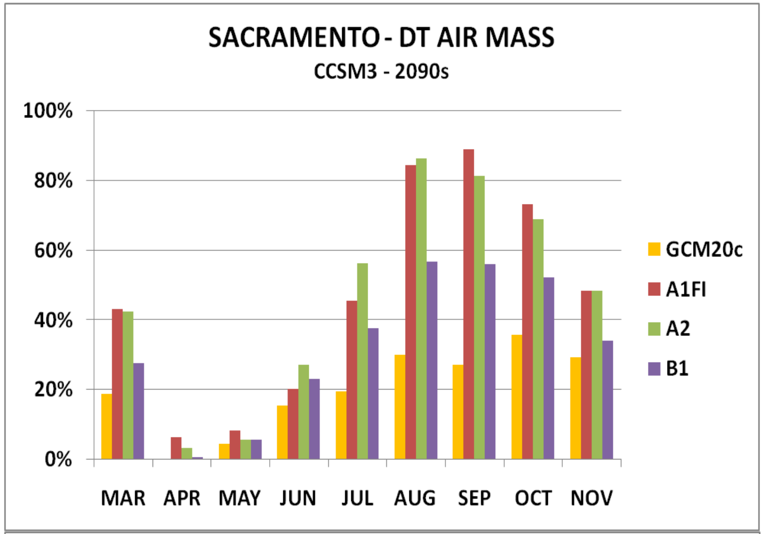


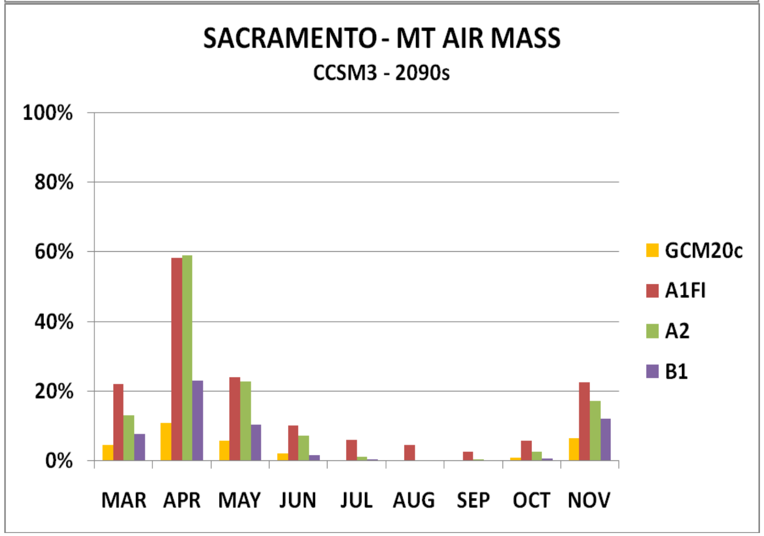
- MT also increases, but much less frequent overall than DT



Future SSC frequency
SACRAMENTO

- DT projected to increase sharply in frequency in late summer
  - Largest in A1FI & A2, but also in B1
  - Broadened seasonality as well
- MT also projected to increase
  - Sharply increases in spring; especially April





Consecutive Day Runs Tropical SSC types

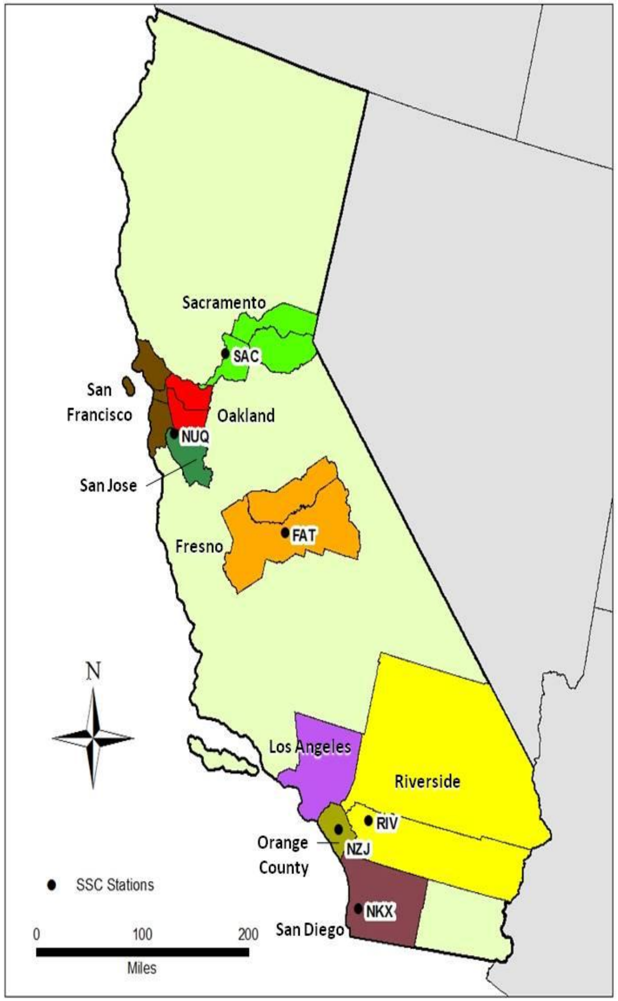
AVERAGE ANNUAL HEAT EVENTS		NNR 20TH CENTURY AVG	CCSM3 20TH CENTURY AVG	CCSM3					
				A1FI		A2		B1	
				2050s	2090s	2050s	2090s	2050s	2090s
Mtn. View	TOTAL OPP. DAYS	52.7	55.3	87.1	142.2	78.5	130.4	70.2	79.3
	7-DAY + EVENTS	1.5	1.8	3.8	5.6	3.4	5.1	2.7	3.4
	14-DAY + EVENTS	0.4	0.4	1.0	1.9	0.4	2.0	0.6	0.7
El Toro	TOTAL OPP. DAYS	44.4	42.5	93.8	143.4	86.8	142.6	68.0	78.6
	7-DAY + EVENTS	1.4	1.1	4.3	7.0	3.8	7.1	2.2	3.6
	14-DAY + EVENTS	0.2	0.2	1.0	2.2	0.5	2.0	0.2	1.0
Riverside	TOTAL OPP. DAYS	106.6	103.2	175.4	206.7	165.6	203.0	142.9	149.7
	7-DAY + EVENTS	4.7	4.3	6.4	6.7	7.5	7.8	6.5	6.4
	14-DAY + EVENTS	1.2	1.1	3.3	2.8	3.1	2.9	2.5	2.3
Sacramento	TOTAL OPP. DAYS	66.7	62.0	137.6	177.9	118.5	169.8	100.0	105.5
	7-DAY + EVENTS	2.0	1.7	6.4	7.8	5.2	7.3	4.7	4.3
	14-DAY + EVENTS	0.2	0.2	1.9	3.3	1.2	2.8	0.8	1.2

Project Outline

1. Project historical and future *atmospheric patterns* and *surface weather types* across the state
2. Assess the historical connection between weather types and heat-related mortality across the state

Estimating population vulnerability

- Data acquired for 9 regions
- Three age groups
  - (<65, 65-74, >74)
- Mortality data 1975-2004
  - All-cause for each region
  - Standardized for season, time
- Population data 1970-2000 + 2005 estimate
  - Interpolated within census



Algorithm development

- Days with Tropical weather type only (DT, MT)
- Stepwise regression
- Dependent variable
  - anomalous mortality
- Independent variables
  - Day in sequence of Tropical weather type
  - Dummy variables for DT and MT
  - Grid cell temperatures
  - Seasonal curves

Mortality relationships

Age Group	MSA	Constant	DT Dummy	MT Dummy	36 N 123 W	36 N 118 W	Inland Curve	Coastal Curve	DIS	TOS
UNDER 65	Fresno	0								
	Los Angeles	-0.189	0.016		0.001					
	Oakland	0.003	0.039	0.038						
	Orange County	0.002	0.015	0.041						
	Riverside	-0.768	0.012			0.003		-0.028		
	Sacramento	-0.548			0.002		-0.018			
	San Diego	0.002	0.021						0.004	
	San Francisco	0.0045								
	San Jose	0.004	0.019							
65 TO 74	Fresno	0.0383								
	Los Angeles	-1.456	0.186		0.005					
	Oakland	0.0884								
	Orange County	-0.012	0.387							
	Riverside	0.0511								
	Sacramento	0.1306								
	San Diego	0.024	0.179							
	San Francisco	0.01	0.293							
	San Jose	0.0466								
OVER 74	Fresno	-0.071	0.57							
	Los Angeles	-12.48	0.841	0.74	0.044			-0.29		
	Oakland	-12.871	1.203	1.302	0.045			-0.374	-0.148	
	Orange County	-0.065	0.583	1.114						
	Riverside	-0.186	0.556	0.927						
	Sacramento	0.299	0.74							-0.002
	San Diego	0.069		0.971					0.123	
	San Francisco	0.362	1.266							-0.002
	San Jose	-10.417	0.942		0.143	-0.103				-0.004

Focus placed on estimating mortality just of those 65 and older

Project Outline

1. Project historical and future *atmospheric patterns* and *surface weather types* across the state
2. Assess the historical connection between weather types and heat-related mortality across the state
3. Use these relationships to project future heat-related mortality

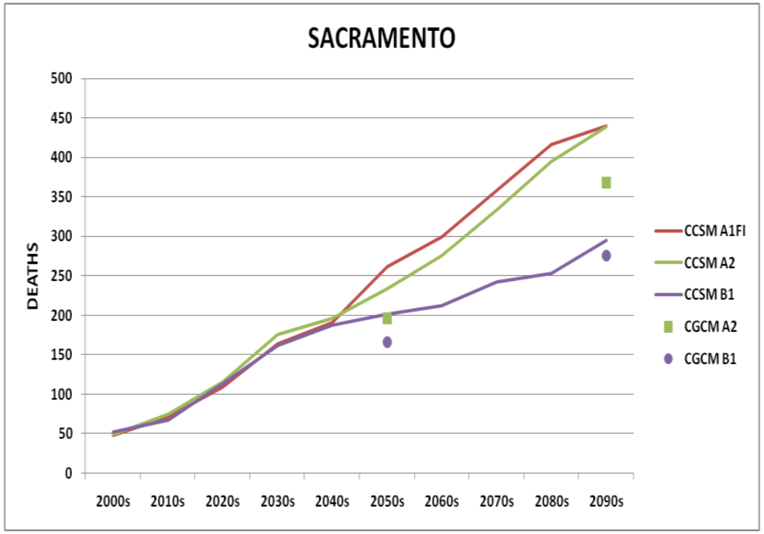
Projecting the future

- Algorithms used with projected SSC and GCM output, and population scenarios
- Population projections

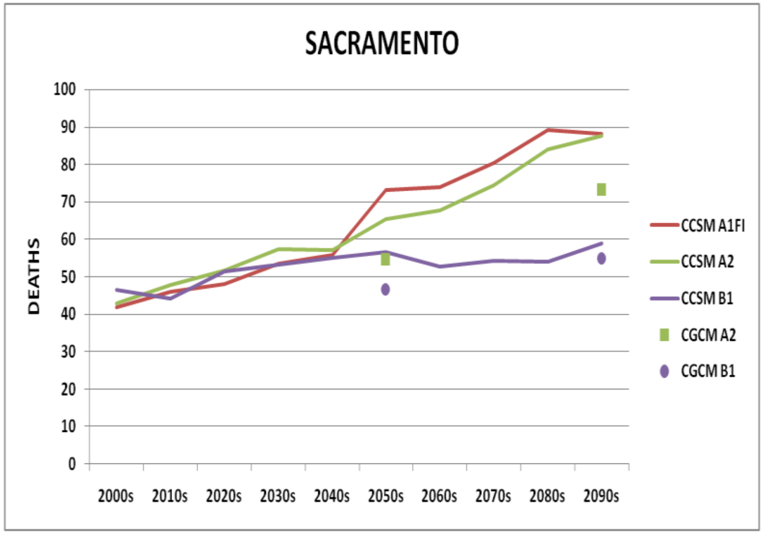
(from Public Policy Institute of California):

  - No growth: Kept at 2000 levels
  - Low growth: 48m by 2100
  - Medium growth: 85m by 2100
  - High growth: 148m by 2100

Mean annual heat-related mortality
SACRAMENTO



Medium population growth



No population growth

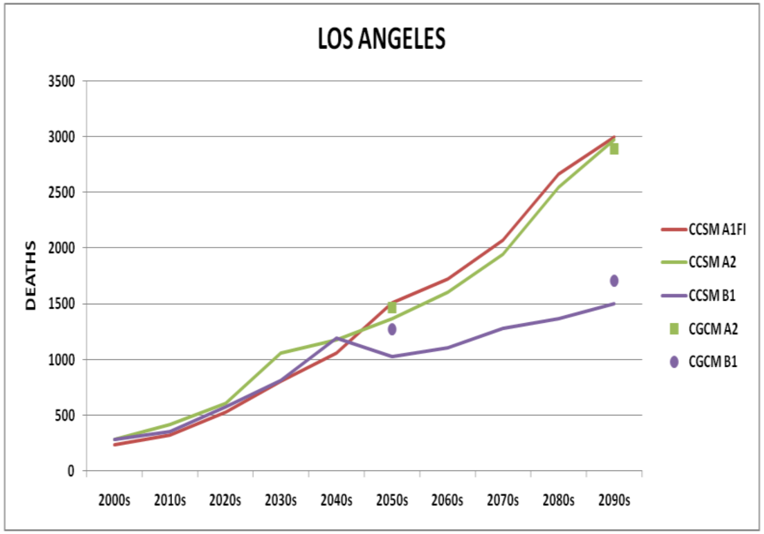
	LOW GROWTH	MEDIUM GROWTH	HIGH GROWTH	NO GROWTH
CCSM A1FI	317	440	727	88
CCSM A2	316	438	725	88
CCSM B1	213	295	488	59
CGCM A2	264	368	610	73
CGCM B1	198	275	457	55

Mean annual heat-related mortality, 2090s

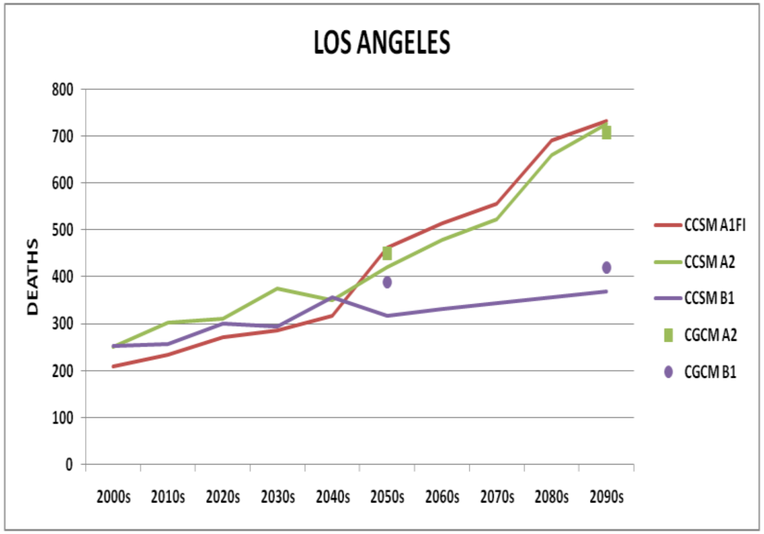
(20th century mean: 27)

Mean annual heat-related mortality

LOS ANGELES



Medium population growth



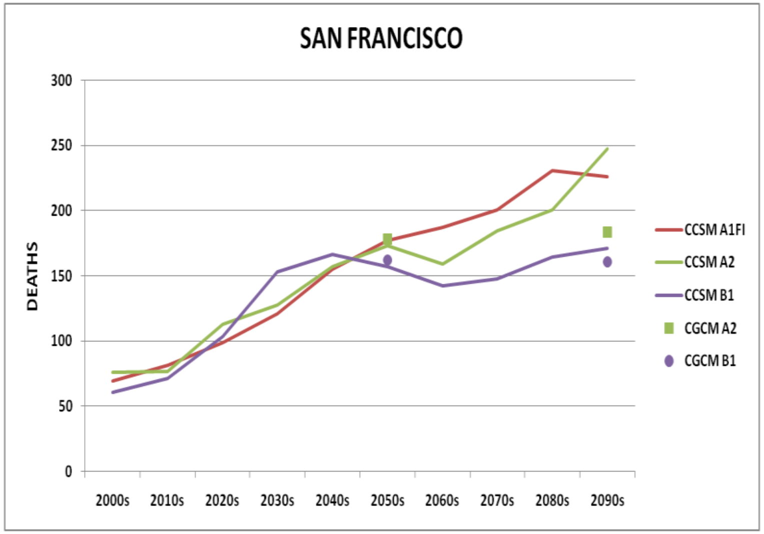
No population growth

	LOW GROWTH	MEDIUM GROWTH	HIGH GROWTH	NO GROWTH
CCSM A1FI	1778	2997	4499	732
CCSM A2	1761	2973	4460	726
CCSM B1	893	1501	2250	368
CGCM A2	1713	2890	4334	707
CGCM B1	1014	1710	2560	420

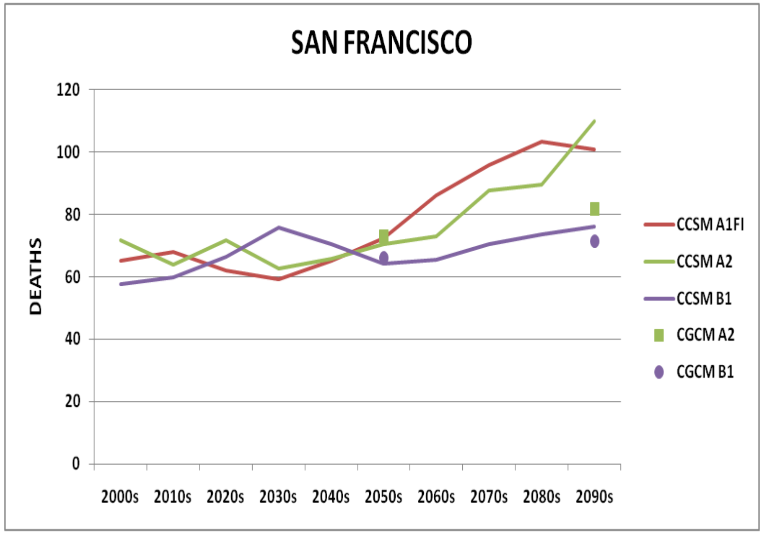
Mean annual heat-related mortality, 2090s

(20th century mean: 165)

Mean annual heat-related mortality
SAN FRANCISCO



Medium population growth



No population growth

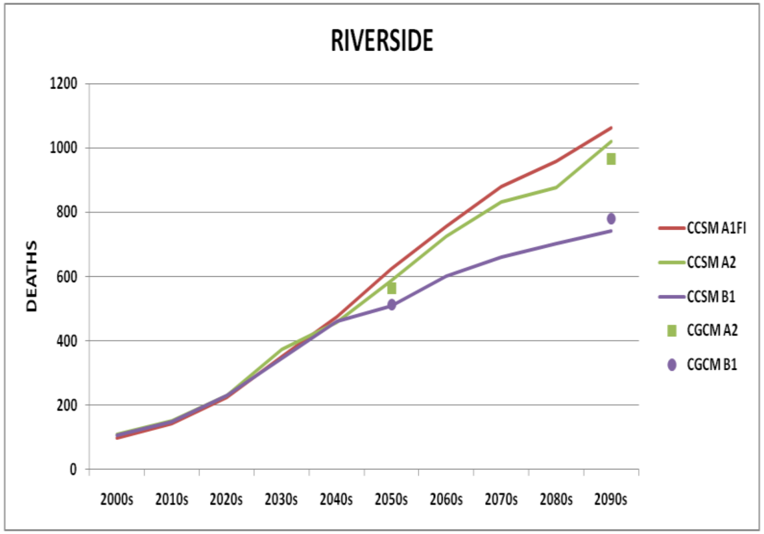
	LOW GROWTH	MEDIUM GROWTH	HIGH GROWTH	NO GROWTH
CCSM A1FI	124	226	387	101
CCSM A2	136	247	424	110
CCSM B1	94	171	293	76
CGCM A2	101	183	314	82
CGCM B1	89	161	275	71

Mean annual heat-related mortality, 2090s

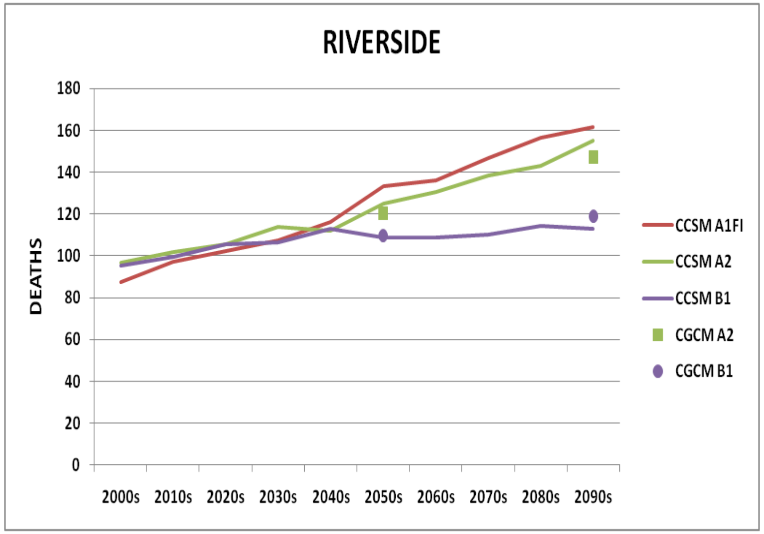
(20th century mean: 53)

Mean annual heat-related mortality

RIVERSIDE



Medium population growth



No population growth

	LOW GROWTH	MEDIUM GROWTH	HIGH GROWTH	NO GROWTH
CCSM A1FI	862	1063	1914	162
CCSM A2	828	1021	1838	155
CCSM B1	602	741	1331	113
CGCM A2	784	966	1736	147
CGCM B1	633	780	1403	119

Mean annual heat-related mortality, 2090s

(20th century mean: 60)

Acclimatization / Adaptation

- Heat-mortality relationship is likely to change
- Quantification of these changes is difficult
- Research suggests ‘added heat-wave effect’

- Two approaches
  - DIS-2: excludes heat-mortality on 1st day of event
  - DIS-4: excludes heat-mortality on 1st, 2nd, 3rd days of event

Acclimatization

SACRAMENTO AND RIVERSIDE

SACRAMENTO	UNACCLIMATIZED	DIS-2 ACCLIMATIZATION		DIS-4 ACCLIMATIZATION	
	Mortality	Mortality	Reduction	Mortality	Reduction
CCSM3 A1FI	440	384	-13%	309	-30%
CCSM3 A2	438	381	-13%	294	-33%
CCSM3 B1	295	225	-24%	139	-53%
CGCM3 A2	368	294	-20%	195	-47%
CGCM3 B1	275	198	-28%	102	-63%
RIVERSIDE	**UNACCLIMATIZED**	**DIS-2 ACCLIMATIZATION**		**DIS-4 ACCLIMATIZATION**	
	Mortality	Mortality	Reduction	Mortality	Reduction
CCSM3 A1FI	1063	967	-9%	838	-21%
CCSM3 A2	1021	919	-10%	782	-23%
CCSM3 B1	741	619	-16%	466	-37%
CGCM3 A2	966	851	-12%	702	-27%
CGCM3 B1	780	642	-18%	458	-41%

Acclimatization

LOS ANGELES AND SAN FRANCISCO

LOS ANGELES	UNACCLIMATIZED	DIS-2 ACCLIMATIZATION		DIS-4 ACCLIMATIZATION	
	Mortality	Mortality	Reduction	Mortality	Reduction
CCSM3 A1FI	2997	2474	-17%	1763	-41%
CCSM3 A2	2973	2386	-20%	1650	-45%
CCSM3 B1	1501	1112	-26%	680	-55%
CGCM3 A2	2890	2327	-19%	1576	-45%
CGCM3 B1	1710	1177	-31%	605	-65%
SAN FRAN.	**UNACCLIMATIZED**	**DIS-2 ACCLIMATIZATION**		**DIS-4 ACCLIMATIZATION**	
	Mortality	Mortality	Reduction	Mortality	Reduction
CCSM3 A1FI	226	162	-28%	98	-56%
CCSM3 A2	247	183	-26%	109	-56%
CCSM3 B1	171	113	-34%	53	-69%
CGCM3 A2	183	123	-33%	67	-63%
CGCM3 B1	161	107	-33%	49	-70%

Summary: SSC changes

SSC Station	Mean Annual			
	Oppressive days		Heat events >10 days	
	20th Cent.	2090s	20th Cent.	2090s
El Toro	43	79 - 147	0.4	1.3 - 4.4
Fresno	84	120 - 184	1.8	3.2 - 5.0
Miramar	54	104 - 179	0.4	1.9 - 5.6
Mountain View	55	79 - 142	0.9	1.4 - 3.2
Riverside	103	150 - 207	2.4	4.0 - 5.0
Sacramento	62	106 - 178	0.6	1.5 - 5.0

Summary: Mortality changes

	Mean Annual Heat Related Mortality (Age 65+)				
	20th century		2090s - Medium Growth		2090s - No Growth
	Unacclimatized	Acclimatized	Unacclimatized	Acclimatized	Unacclimatized
Fresno	15	11	192 - 266	162 - 244	26 - 36
Los Angeles	165	102	1501 - 2997	1112 - 2474	368 - 732
Oakland	49	28	413 - 726	248 - 472	85 - 149
Orange County	44	27	395 - 742	294 - 602	105 - 194
Riverside	60	45	741 - 1063	619 - 967	113 - 162
Sacramento	27	18	275 - 440	198 - 384	55 - 88
San Diego	68	47	750 - 1865	610 - 1725	207 - 511
San Francisco	53	33	161 - 247	107 - 183	71 - 110
San Jose	27	18	256 - 411	176 - 320	44 - 69
TOTAL	**508**	**329**	**4684 - 8757**	**3526 - 7371**	**1074 - 2051**

Uncertainties in the projections

- GCM ability
- Scenario uncertainty
  - Emissions
  - Population
- The impact of acclimatization

Key conclusions (1)

- Heat-mortality relationship most significant for those >74 years old
  - Fastest growing demographic
- Population growth increases vulnerability
- Large rises in DT and MT occurrence
  - DT more inland, MT more along coast
- Very large increases in long episodes
  - Up to five events per year of at least 10 days in some locations

Key conclusions (2)

- GCMs generally consistent
- Large variability by emissions scenario
  - General divergence after 2040s
  - B1 shows increased vulnerability leveling off after 2050s (esp. southern California)
- Acclimatization may significantly reduce heat-related mortality
  - But in all instances, still grows significantly due to demographic changes

Recommendations

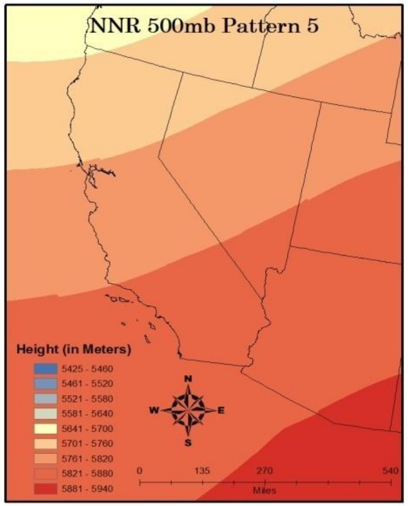
- Implementation of heat-warning systems
- Development of heat-health task force in major urban areas
- Further study of potential adaptation mechanisms

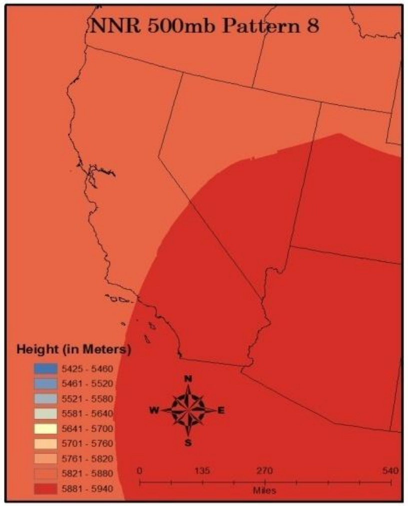
PI: Scott Sheridan (ssherid1@kent.edu)

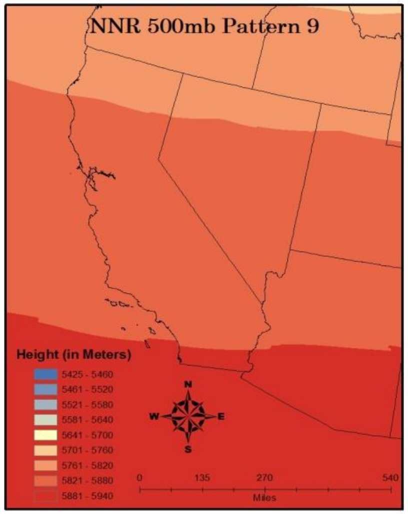
EXTRA SLIDES

Historical Circulation Patterns: 500mb heights

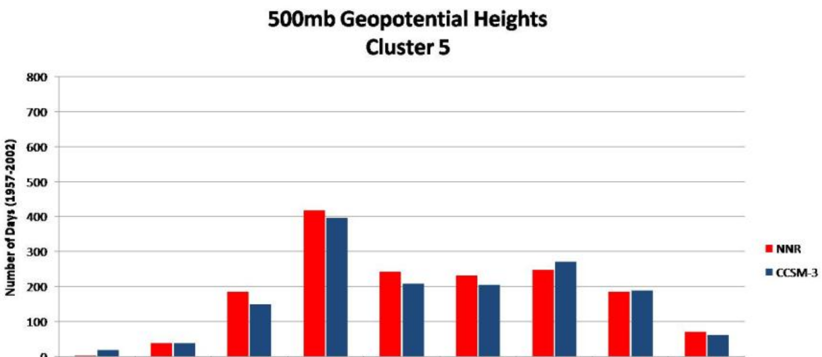
- Three summer-dominant patterns
  - Patterns 5, 8, 9
    - Account for 98% of July and August days





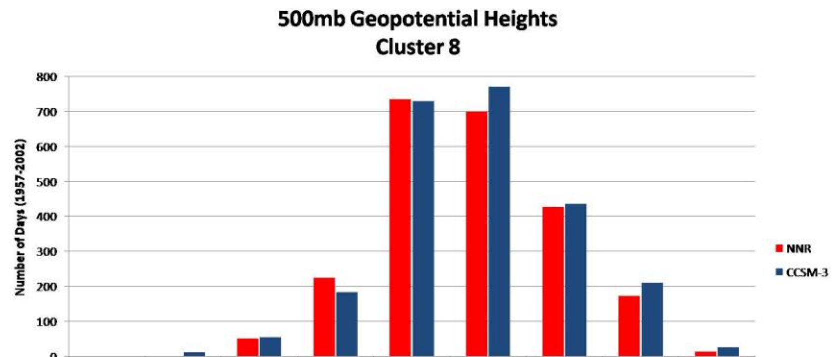


Historical Circulation Patterns: 500mb heights



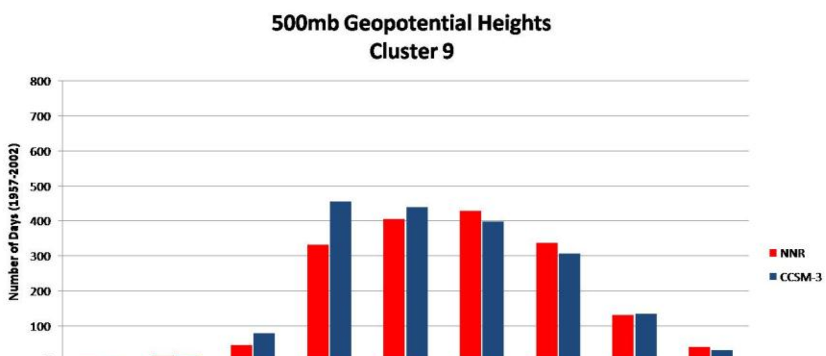
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
NNR	4	40	187	418	243	232	249	187	71
CCSM-3	19	39	150	397	209	206	272	189	62

MONTH



	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
NNR		1	51	225	736	699	428	173	13
CCSM-3		12	56	185	730	771	436	212	27

MONTH

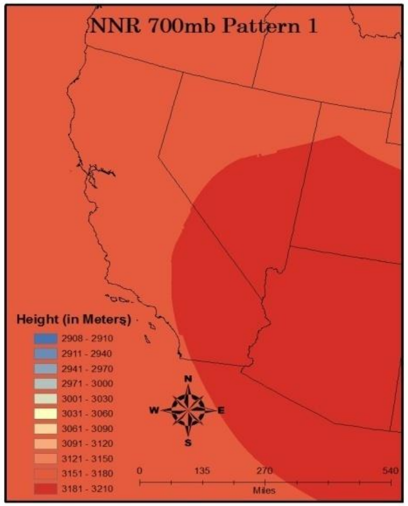


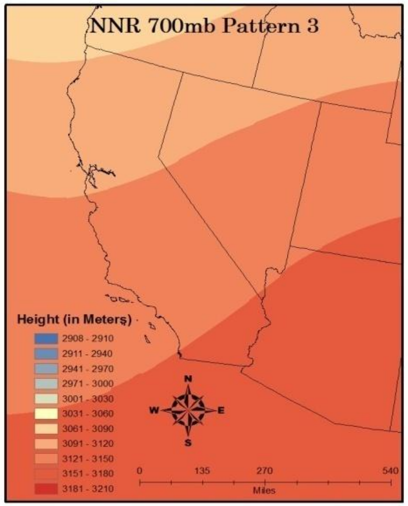
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
NNR	4	13	47	332	407	429	339	132	41
CCSM-3	5	10	81	457	441	400	308	136	33

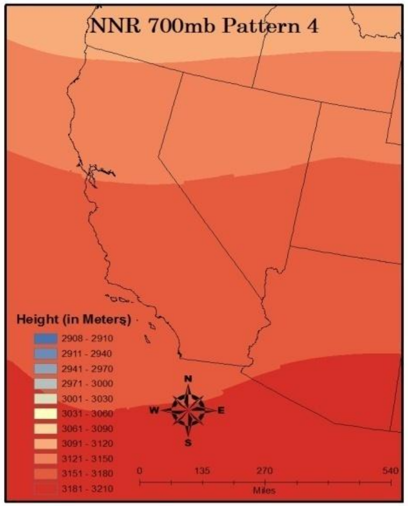
MONTH

Historical Circulation Patterns: 700mb heights

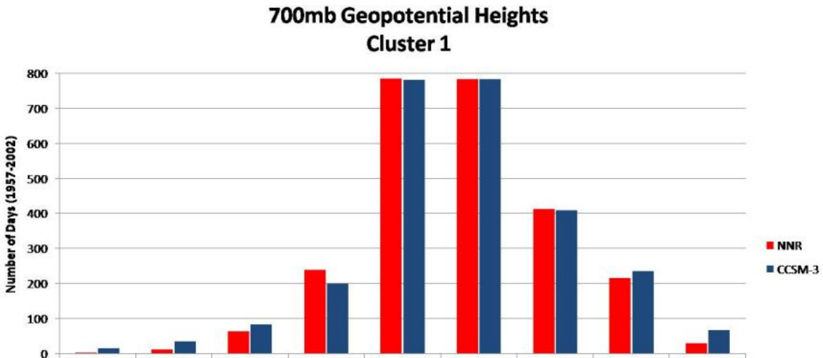
- Three summer-dominant patterns
  - Patterns 1, 3, 4
    - Account for 95% of July and August days





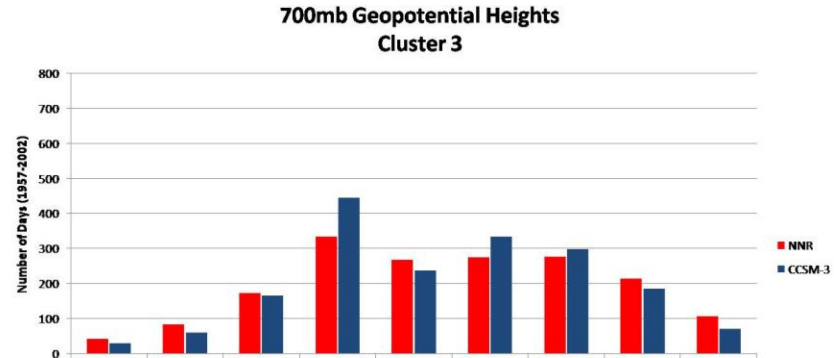


Historical Circulation Patterns: 700mb heights



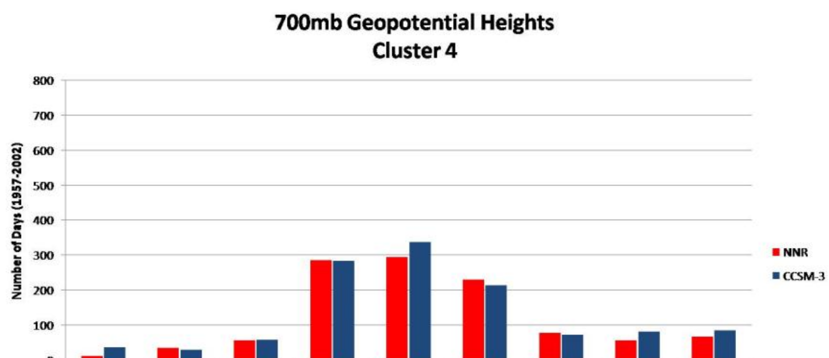
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
NNR	4	13	65	239	786	784	413	216	30
CCSM-3	16	36	85	200	782	783	409	237	68

MONTH



	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
NNR	43	84	174	334	268	275	278	214	107
CCSM-3	31	60	166	445	238	335	298	186	72

MONTH

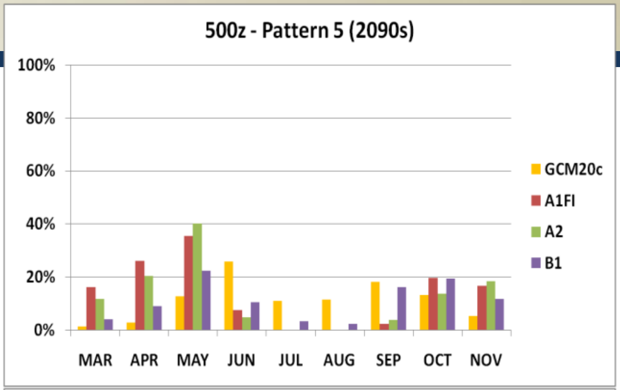


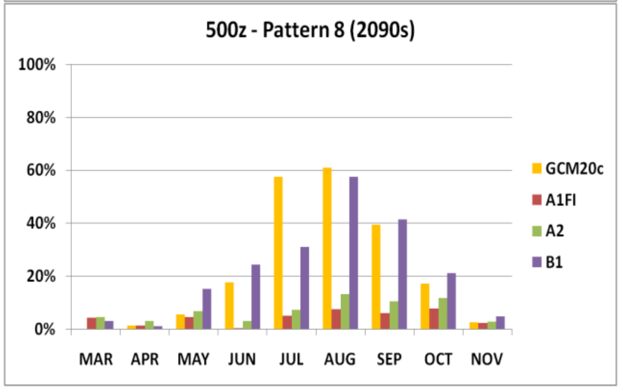
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
NNR	13	35	57	287	296	231	78	57	68
CCSM-3	37	31	59	285	338	215	74	83	86

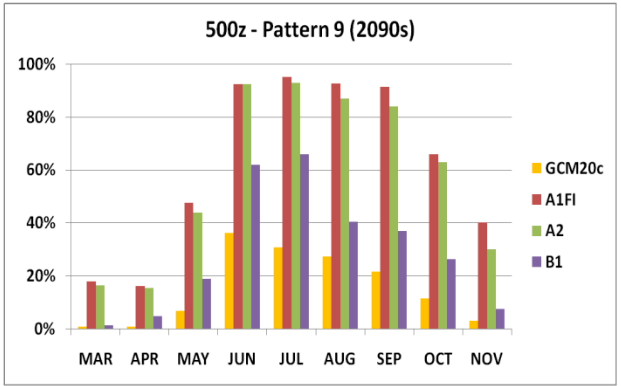
MONTH

Future Patterns: 500mb heights

- Pattern 5: shifts to a spring-dominant pattern
  - Secondary peak in autumn
- Pattern 8: decreases in future frequency
- Pattern 9: becomes the most common summer pattern
  - Occurs over 90% of summer days by 2090s in A1FI scenario

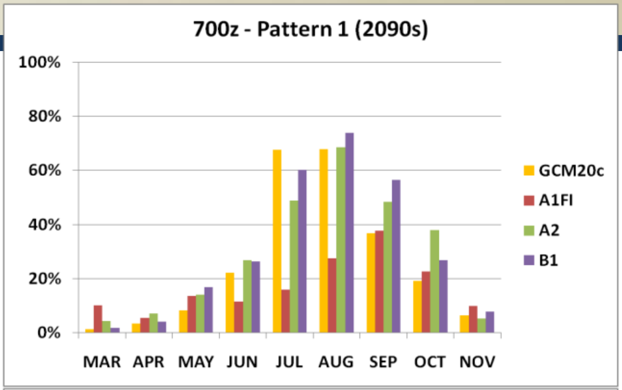


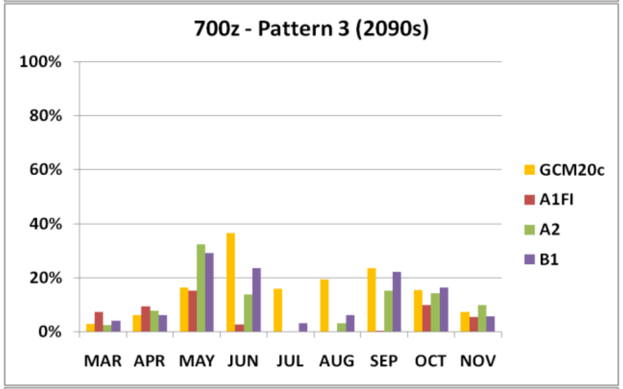


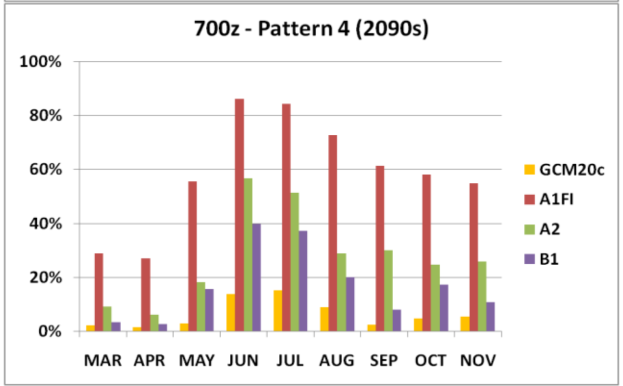


Future Patterns: 700mb heights

- Pattern 1: becomes secondary pattern in summer (to pattern 4) in A1FI by 2090s
  - Stays primary pattern in B1
- Pattern 3: no longer a summer pattern
  - Begins occurring in Spring
  - Under B1, strong secondary peak in autumn
- Pattern 4: Occurs much more often
  - Especially frequent in summer
  - Overtakes pattern 1 in frequency in high emissions scenarios
  - Not as common in B1

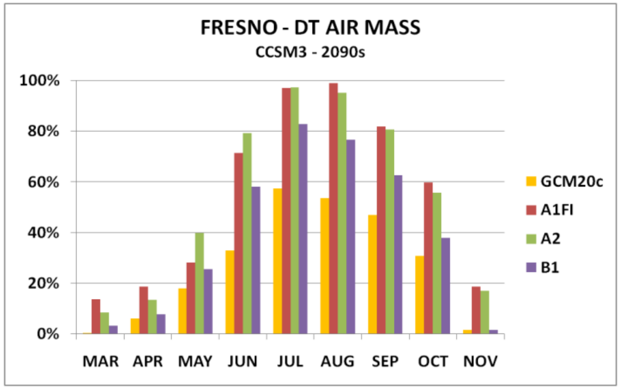


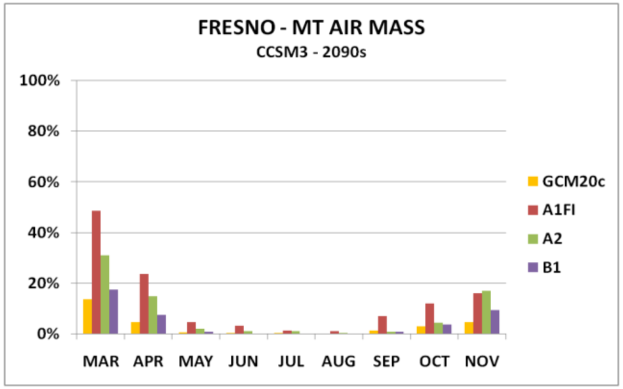




FRESNO

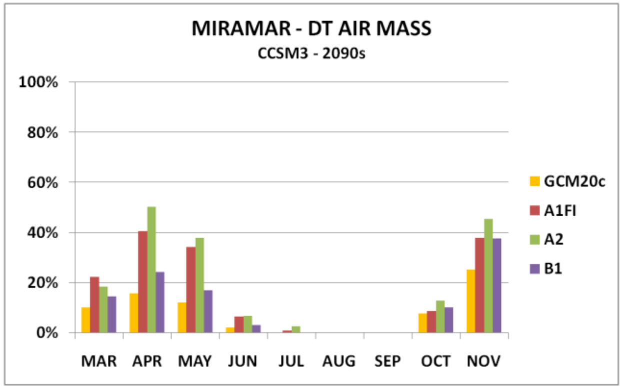
- DT weather type is most frequent
- Becomes more frequent in future
  - A1FI 2090s: close to 100% frequency in summer
- MT is rare and will remain rare in summer
  - Could rise increase markedly in early spring

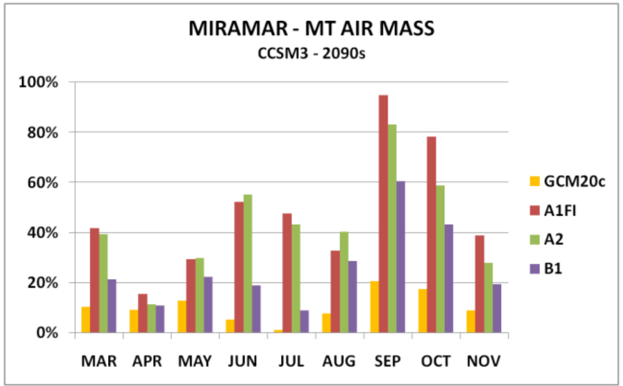




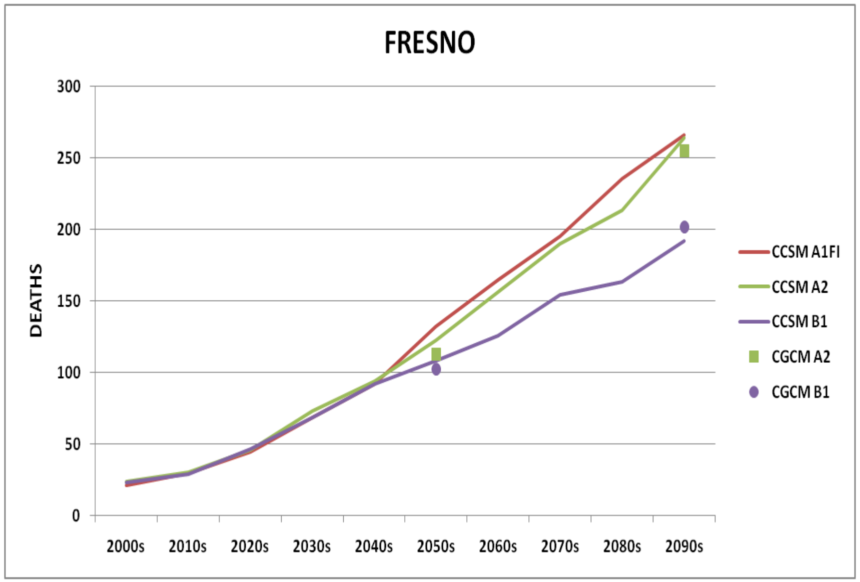
MIRAMAR

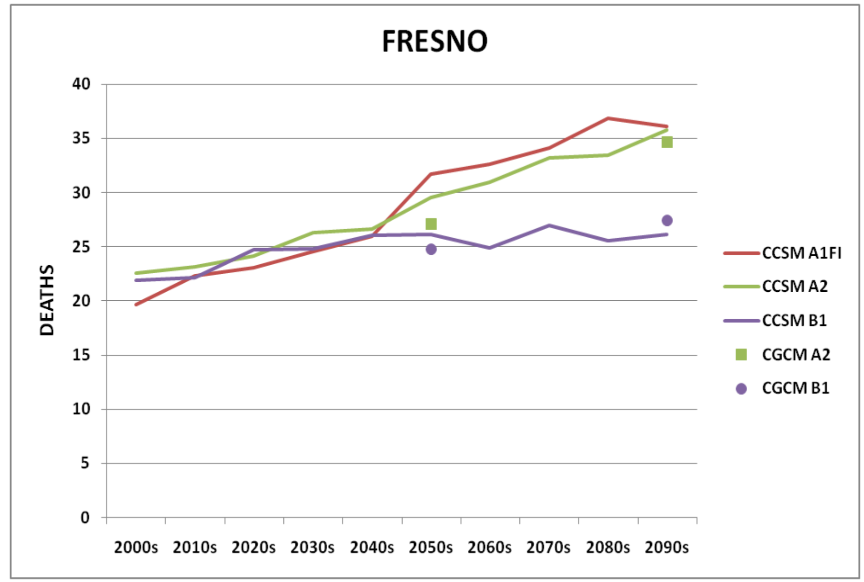
- Summer DT frequency is very low, and will remain low
  - Potential doubling in late spring under A2
- MT occurs in early and late summer and transitional seasons
  - Will occur substantially more often in future
    - Including the summer months
    - Especially in the A1FI and A2 scenarios





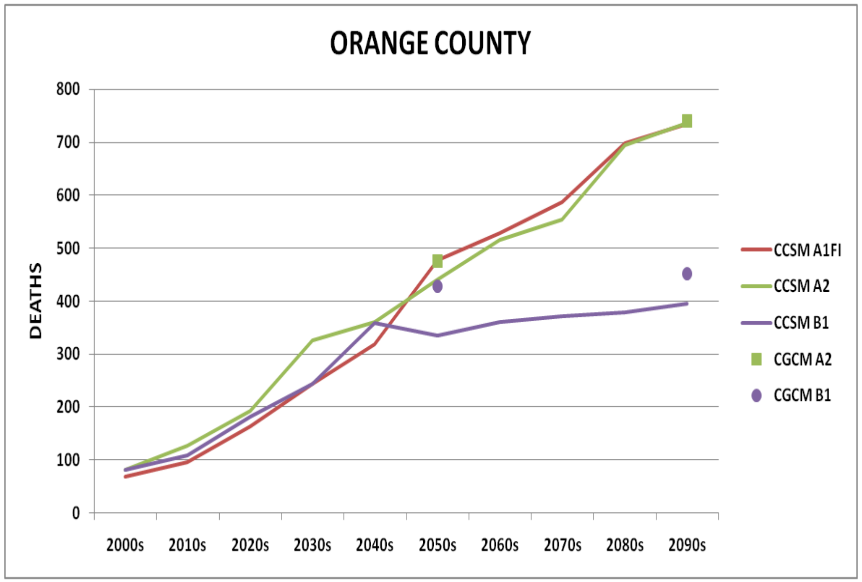
Fresno

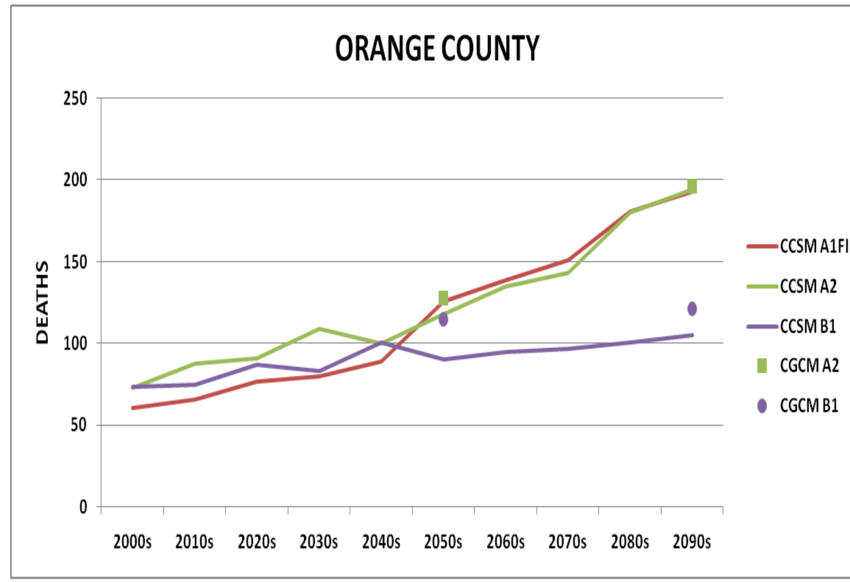




FRESNO								
	2050s				2090s			
	NOT ACC.	ACC.	DIFF	% DIFF	NOT ACC.	ACC.	DIFF	% DIFF
CCSM3 A1FI	132	117	-15	-12%	266	244	-22	-8%
CCSM3 A2	123	106	-17	-14%	264	237	-27	-10%
CCSM3 B1	109	92	-16	-15%	192	162	-30	-16%
CGCM3 A2	113	93	-20	-18%	255	220	-36	-14%
CGCM3 B1	102	82	-20	-20%	202	163	-39	-19%
20c AVG.	15	11	-3	-23%				

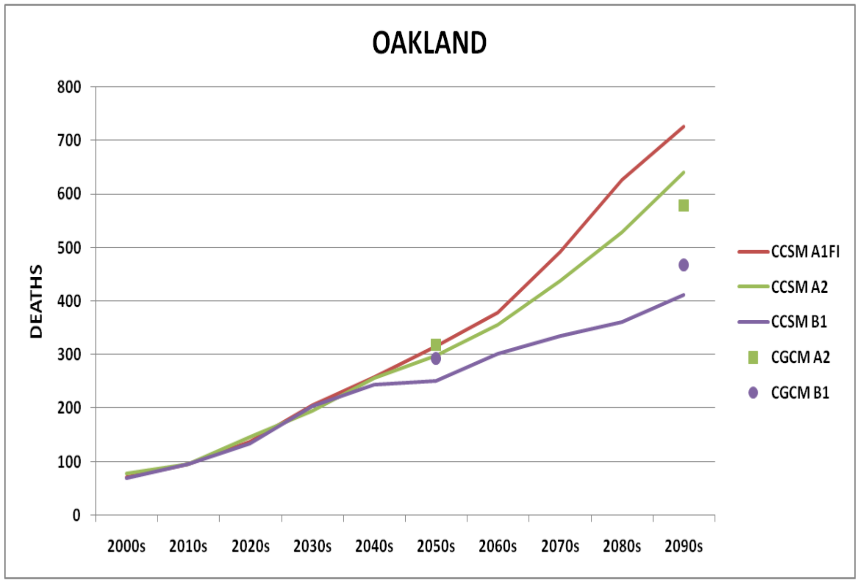
Orange County

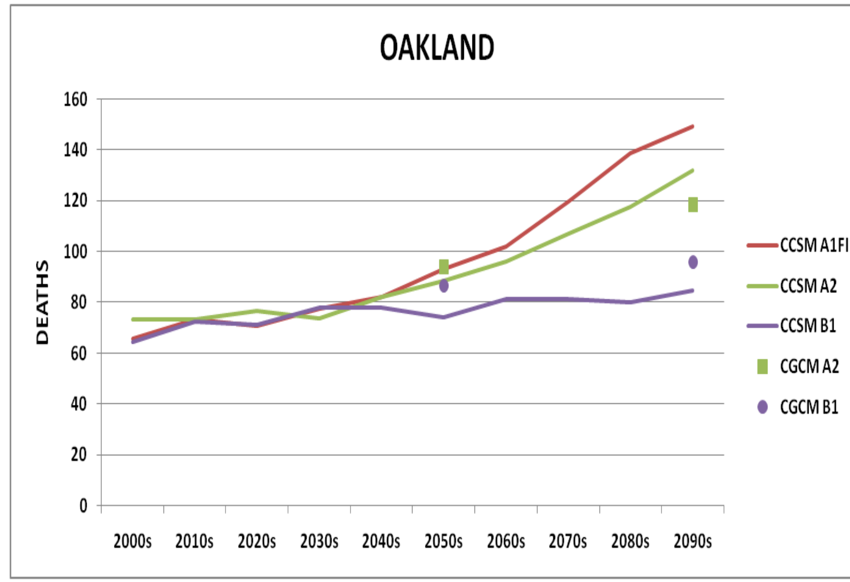




ORANGE COUNTY								
	2050s				2090s			
	NOT ACC.	ACC.	DIFF	% DIFF	NOT ACC.	ACC.	DIFF	% DIFF
CCSM3 A1FI	477	360	-117	-25%	735	602	-132	-18%
CCSM3 A2	441	313	-128	-29%	737	587	-150	-20%
CCSM3 B1	335	219	-116	-35%	395	294	-102	-26%
CGCM3 A2	476	348	-128	-27%	742	594	-148	-20%
CGCM3 B1	428	312	-116	-27%	452	304	-148	-33%
20c AVG.	44	27	-17	-39%				

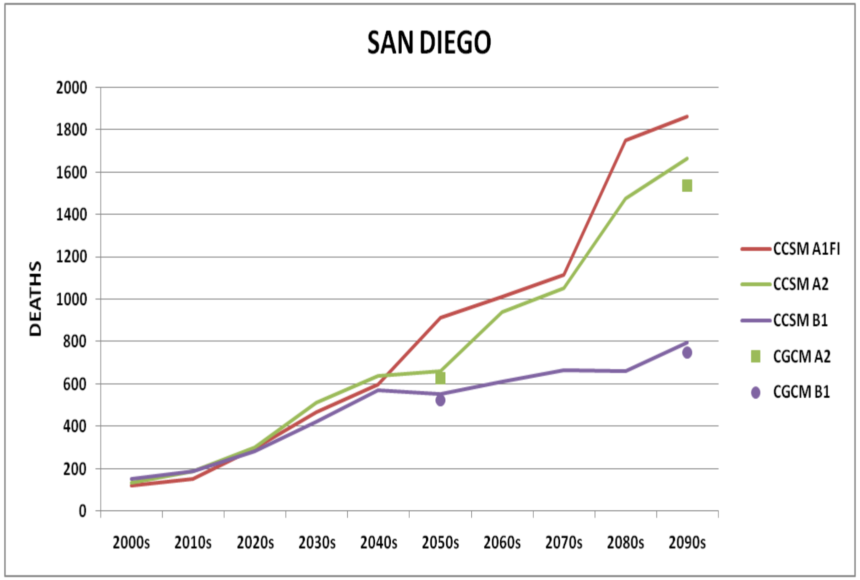
Oakland

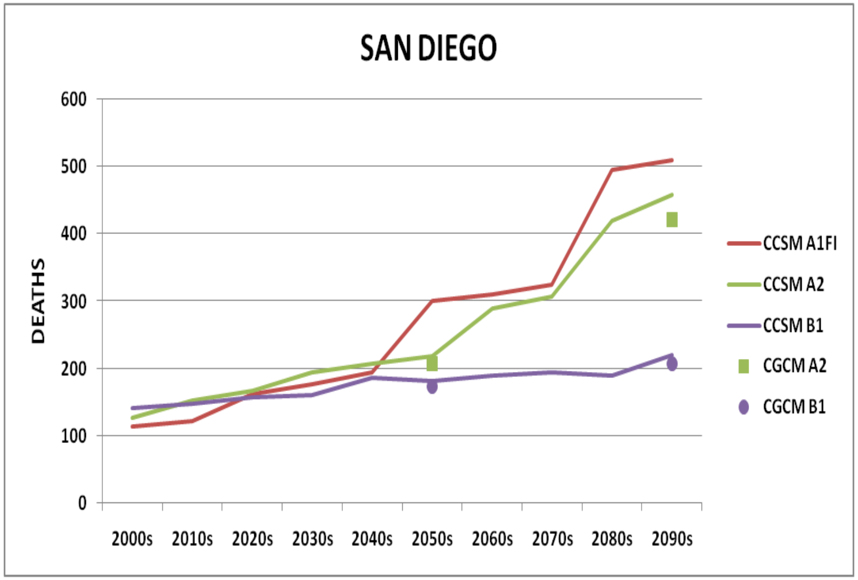




OAKLAND								
	2050s				2090s			
	NOT ACC.	ACC.	DIFF	% DIFF	NOT ACC.	ACC.	DIFF	% DIFF
CCSM3 A1FI	315	190	-125	-40%	726	472	-254	-35%
CCSM3 A2	299	172	-127	-42%	641	419	-223	-35%
CCSM3 B1	252	144	-108	-43%	413	248	-165	-40%
CGCM3 A2	319	183	-136	-43%	579	351	-228	-39%
CGCM3 B1	294	161	-133	-45%	468	271	-196	-42%
20c AVG.	49	28	-21	-43%				

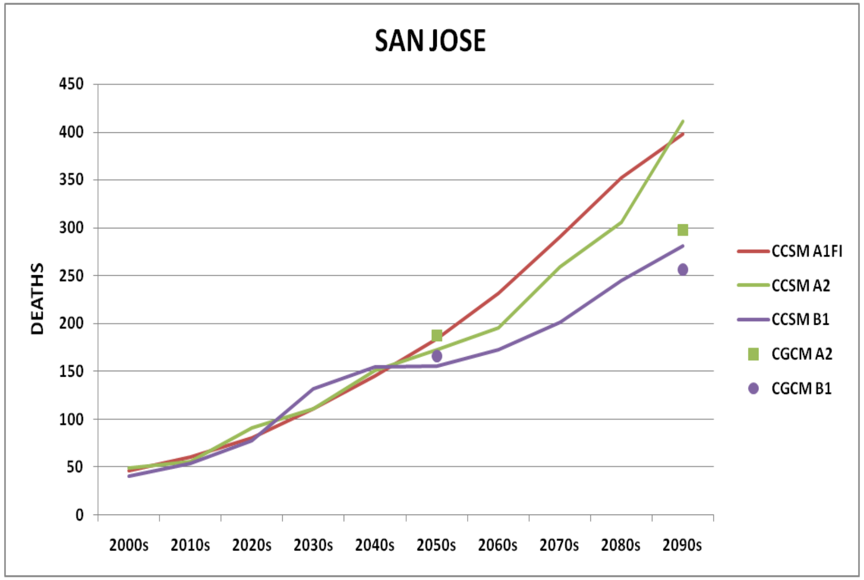
San Diego

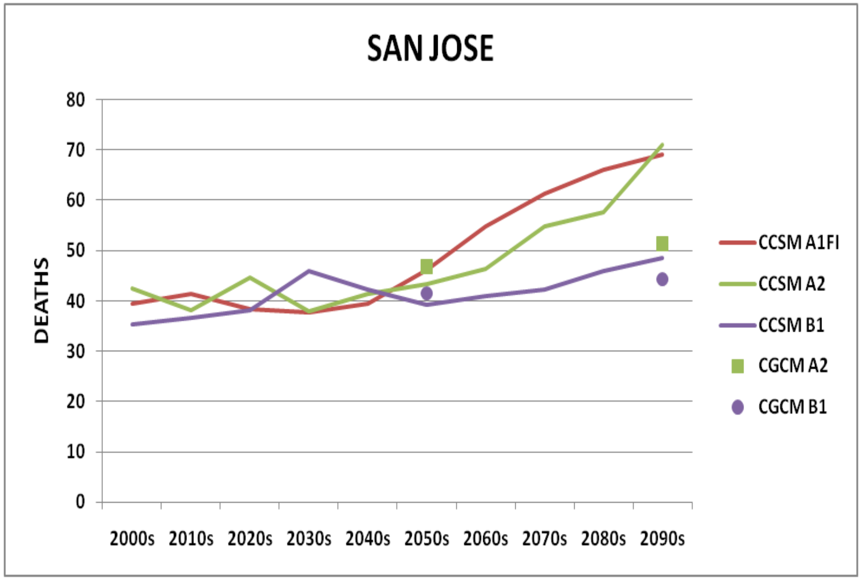




SAN DIEGO								
	2050s				2090s			
	NOT ACC.	ACC.	DIFF	% DIFF	NOT ACC.	ACC.	DIFF	% DIFF
CCSM3 A1FI	916	785	-131	-14%	1865	1725	-140	-7%
CCSM3 A2	663	542	-121	-18%	1667	1526	-141	-8%
CCSM3 B1	555	451	-104	-19%	797	667	-131	-16%
CGCM3 A2	628	515	-113	-18%	1535	1387	-149	-10%
CGCM3 B1	525	421	-104	-20%	750	610	-140	-19%
20c AVG.	68	47	-20	-30%				

San Jose





SAN JOSE								
	2050s				2090s			
	NOT ACC.	ACC.	DIFF	% DIFF	NOT ACC.	ACC.	DIFF	% DIFF
CCSM3 A1FI	184	129	-55	-30%	398	302	-96	-24%
CCSM3 A2	172	116	-57	-33%	411	320	-92	-22%
CCSM3 B1	156	106	-51	-32%	281	201	-80	-29%
CGCM3 A2	187	127	-60	-32%	297	205	-92	-31%
CGCM3 B1	166	103	-62	-38%	256	176	-80	-31%
20c AVG.	27	18	-9	-33%				